Impact Area Groundwater Study Program

DRAFT

Revised Draft Technical Team Memorandum 01-17

Feasibility Study

Demo 1 Groundwater Operable Unit

Camp Edwards
Massachusetts Military Reservation
Cape Cod, Massachusetts

May 20, 2004

Prepared for:

U.S. Army Corps of Engineers
New England District
Concord, Massachusetts
for
U.S. Army / National Guard Bureau
Impact Area Groundwater Study Program
Camp Edwards, Massachusetts

Prepared by:

AMEC Earth & Environmental, Inc
Westford, Massachusetts
Contract No. DAHA92-01-D-0006

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DISCLAIMER

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CERTIFICATION:

I hereby certify that the enclosed Report, shown and marked in this submittal, is that proposed to be incorporated with Contract Number DAHA92-01-D-0006-DB01. This Document has been prepared in accordance with USACE Scope of Work and is hereby submitted for Government approval.

Reviewed by:

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Contractor Quality System Manager   Date

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AMEC Project Manager   Date

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AMEC Program Manager   Date

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ACRONYMS AND ABBREVIATIONS

2,4-DANT	2,4-diamino-6-nitrotoluene
2,6-DANT	2,6-diamino-4-nitrotoluene
2,4-DNT	2,4-dinitrotoluene
2A-DNT	2-amino-4,6-dinitrotoluene
4A-DNT	4-amino-2,6-dinitrotoluene
AMEC	AMEC Earth and Environmental
AO1	Administrative Order Number 1 (SDWA 1-97-1019)
AO2	Administrative Order Number 2 (SDWA 1-97-1030)
AO3	Administrative Order Number 3 (SDWA 1-2000-0014)
AOC	Area of Concern
BBM	Buzzards Bay Moraine
bgs	below ground surface
bwt	below water table
CEC	Cation Exchange Capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMR	Code of Massachusetts Regulations
COC	Contaminant of Concern
COPC	Contaminant of Potential Concern
Demo 1	Demolition Area 1
DEP	Massachusetts Department of Environmental Protection
DNT	Dinitrotoluene
DNX	hexahydro-1,3-dinitroso-5-mononitro-1,3,5-triazine
DP OP##	Demo 1 Piezometer, Opening Pond
DP SG	Demo 1 Staff Gauge
DWEL	Drinking Water Equivalent Level
EBCT	Empty Bed Contact Time
EOD	Explosive Ordnance Disposal
EM	Electromagnetic
EPA	United States Environmental Protection Agency
ETR	Extraction, Treatment, and Recharge
FBR	Fluidized Bed Reactor
FS	Feasibility Study
FSP	Field Sampling Plan
FSWP	Feasibility Study Work Plan
ft	feet or foot
ft^3	cubic feet or cubic foot
GAC	Granular Activated Carbon
GP	Gun Position
gpm	gallons per minute
gpm/ft^2	gallons per minute per square feet
HASP	Health and Safety Plan
HELP	Hydrologic Evaluation Landfill Performance model
HMX	octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine

ACRONYMS AND ABBREVIATIONS (Cont'd)

IAGWSP	U.S. Army/National Guard Bureau's Impact Area Groundwater Study Program
IART	Impact Area Review Team
IRA	Immediate Response Action
ITE	Innovative Technology Evaluation
IX	Ion Exchange
J	Laboratory data qualifier denoting an estimated value
LTGM	Long Term Groundwater Monitoring
MAARNG	Massachusetts Army National Guard
MCL	Maximum Contaminant Level
MCP	Massachusetts Contingency Plan
MDL	Method Detection Limit
mg/kg	milligram per kilogram
mg/L	milligrams per liter
mm	millimeter
MMR	Massachusetts Military Reservation
MNX	hexahydro-1-mononitroso-3,5-dinitro-1,3,5-triazine
MODFLOW	Modular Three-Dimensional Finite Difference Groundwater Flow Model
MPP	Mashpee Pitted Plain
MW-#	monitoring well identification number
mV	milliVolts
ND	Non-Detect
NGVD	National Geodetic Vertical Datum
OB/OD	Open Burn and Open Detonation
OCDD	Octachlorinated Dioxin
OCDF	Octachlorinated Furan
O&M	Operation and Maintenance
OU	Operable Unit
PCE	perchloroethylene or tetrachloroethylene
PCN	Polychlorinated Naphthalene
PDA	Photo Diode Array
pg/L	picograms per liter
PPE	Personal Protective Equipment
PRG	Preliminary Remediation Goal
PSI	Post-Screening Investigation
PTO	Particle Tracking Optimization
RA	Remedial Action
RAM	Release Abatement Measure
RCRA	Resource Conservation and Recovery Act
RCS-1	Reportable Concentration for Soil for a category S1 soil
RD	Remedial Design
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine/Royal Demolition Explosive
RRA	Rapid Response Action

ACRONYMS AND ABBREVIATIONS (Cont'd)

RSSCT	Rapid Small-Scale Column Test
SDWA	Safe Drinking Water Act
SM	Sandwich Moraine
SPEIM	System Performance and Environmental Impact Monitoring
SVOC	Semi-Volatile Organic Compounds
TEQ	Toxic Equivalency
TM	Technical Team Memorandum
TMR	Telescopic Mesh Refinement
TNT	2,4,6-trinitrotoluene
TNX	hexahydro-1,3,5-trinitroso-1,3,5-triazine
TOC	Total Organic Carbon
TOM	Top-of-Mound
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
USGS	United States Geological Survey
UXO	Unexploded Ordnance
UXORM	Unexploded Ordnance Related Material
VOC	Volatile Organic Compound

EXECUTIVE SUMMARY

This Revised Draft Feasibility Study (FS) presents the evaluation of alternatives to remediate explosives and perchlorate contamination in groundwater at Demolition Area 1 (Demo 1) at Camp Edwards, pursuant to United States Environmental Protection Agency (EPA) Administrative Orders Safe Drinking Water Act (SDWA) I-97-1019 (AO1) and 1-2000-0014 (AO3).

Demo 1 is located north of Pocasset Forestdale Road and south of the Impact Area at Camp Edwards, west of Turpentine Road and east of Frank Perkins Road. Demolition training and explosive ordnance disposal at Demo 1 included the destruction of various types of ordnance using explosive charges of C4, 2,4,6-trinitrotoluene (TNT), and detonation cord from the mid 1970's to the late 1980's. The predominant explosive compounds used in demolition munitions are hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) followed by TNT. Perchlorate has also been detected in groundwater. Perchlorate (ClO_4^-) originates as a contaminant in the environment from the solid salts of ammonium, potassium, or sodium perchlorate. Ammonium and potassium perchlorate are manufactured for use as the oxidizer component and primary ingredient in solid propellant for rockets, missiles, and fireworks, in addition to being used in some delay compositions, flares, signaling devices, other pyrotechnics, smokes, and tracers.

Seven explosive and propellant compounds (RDX, TNT, octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine [HMX], 2-amino-4,6-dinitrololuene [2A-DNT], 4-amino-2,6-dinitrotoluene [4A-DNT], perchlorate and 2,4-dinitrotoluene [2,4-DNT]) have been consistently detected in groundwater and are identified as the contaminants of concern (COCs) in groundwater for the Demo 1 Groundwater Operable Unit. These contaminants are all directly related to past demolition and disposal activities and have been detected in soil at Demo 1.

RDX and TNT have been detected in groundwater at Demo 1 at maximum concentrations of 370 micrograms per liter (μg/L) and 16 μg/L, respectively. Perchlorate has been detected in groundwater at Demo 1 at a maximum concentration of 500 μg/L. The measured extent of the perchlorate plume is approximately 9,200 feet long and 1,400 feet wide, and the measured extent of the RDX plume is approximately 4,600 feet long and 650 feet wide. The RDX plume and all other COC plumes are contained within the perchlorate plume.

The overall Remedial Action Objective for groundwater at Demo 1 is to protect and restore a localized contaminated area within the sole source aquifer. The specific Remedial Action Objective as required by AO3 is to:

> *Prevent potential ingestion and inhalation of water containing COCs (RDX, HMX, 2,4-DNT, 2A-DNT, 4A-DNT, TNT and perchlorate) in excess of background levels (to the extent technically feasible), federal maximum contaminant levels (MCLs), Health Advisories, Drinking Water Equivalent Levels (DWELs), or an unacceptable excess lifetime cancer risk or non-cancer Hazard Index*.

The EPA Lifetime Health Advisory for RDX and TNT in drinking water is 2 μg/L. There is no Federal Maximum Contaminant Level or EPA Lifetime Health Advisory for perchlorate. A “relevant standard” of 1.5 μg/L had been provided by EPA (USEPA, 2001) for the purposes of developing and evaluating alternatives in feasibility studies required by AO3, however, this was rescinded in February 2003.

In January 2003, EPA (EPA, 2003) issued a memorandum re-affirming 1999 interim guidance that results in a provisional risk-based standard range from 4 to 18 μg/L for perchlorate. The range (4-18 μg/L) is considered to be protective based on recent, ongoing analyses and taking into account the most sensitive receptors, and therefore no additional adjustment for childhood exposure is needed.

In April 2002, the Massachusetts Department of Environmental Protection (DEP) issued a ‘Massachusetts Interim Drinking Water Advice for Perchlorate’ to the Bourne Water District in response to the low concentrations of perchlorate detected in groundwater samples collected from wells within the Monument Beach Well Field. The DEP recommended that “pregnant women, infants, children up to the age of twelve, and individuals with hypothyroidism avoid drinking water containing concentrations of perchlorate exceeding 1 μg/L”. In addition, the DEP plans to establish a numeric standard for perchlorate in Spring 2004. The Army has agreed to meet numeric standards or remediate to a level below such standards if feasible, where such standards are applicable or relevant and appropriate, and promulgated or adopted in the future.

The IAGWSP is currently implementing a groundwater Rapid Response Action (RRA) at Demo 1. The purpose of the groundwater RRA is to begin removing dissolved contaminant mass in the plume while continuing to evaluate the feasibility of comprehensive remedial actions and determining a comprehensive remedial action. The RRA includes extraction and treatment of contaminated groundwater from two areas within the plume: one near Frank Perkins Road and another at Pew Road, between Estey and Pocasset Forestdale Roads.

A wide range of potential remedial technologies and process options were identified and screened based upon their potential ability to remediate the COCs and meet the Remedial Action Objectives in the Draft FS (AMEC, 2001d). Process options were then combined into remedial alternatives that represented a range of treatment and/or containment options to address the remedial action goals. The evaluation conducted in the Draft FS (AMEC, 2001d) formed the basis for the selection of the extraction, treatment and recharge (ETR) components for the groundwater RRA Plan. Because the groundwater RRA will be in operation prior to implementation of the comprehensive remedial action, the groundwater RRA ETR components are incorporated, where feasible, into each of the comprehensive remedial alternatives.

The six comprehensive remedial alternatives developed for the Demo 1 Groundwater Operable unit include:

- Alternative 1 – Minimal Action. Alternative 1 provides a minimal action alternative for comparison with other alternatives. This alternative includes institutional controls and long-term monitoring only.

- Alternative 2 – Baseline. Alternative 2 provides a baseline alternative for comparison with other alternatives. This alternative includes the continued operation of the groundwater RRA ETR Systems and would achieve background concentrations for the COCs in 50 years, according to groundwater modeling performed during this FS. Alternative 2 would entail pumping groundwater at a total flow rate of approximately 320 gallons per minute (gpm) from two locations, treatment via ion exchange (IX) resin to remove perchlorate and granular activated carbon (GAC) media to remove explosive compounds, and recharge of treated water via three injection wells. A permanent structure would be constructed to house the treatment system. This alternative also includes long-term groundwater monitoring and institutional controls.

- Alternative 3 - Background. Alternative 3 includes a total of four extraction wells (including the two existing groundwater RRA extraction wells) located along the plume axis and pumping at a combined flow rate of 472 gpm. Alternative 3 provides an alternative that would be expected to achieve background concentrations for the COCs in less than 30 years according to groundwater modeling performed during this FS. Similar to Alternative 2, a combination of IX resin and GAC media would be utilized to treat the extracted water, however a fourth injection well would be added to recharge the treated water to the aquifer. This alternative also includes long-term groundwater monitoring and institutional controls.

- Alternative 4 - 10 Year. Alternative 4 includes a total of five extraction wells (including the two existing groundwater RRA extraction wells) located along the plume axis and pumping at a combined flow rate of 1,417 gpm. This alternative is the most aggressive cleanup scenario evaluated in this FS, designed to achieve regulatory and risk-based standards for the COCs within 10 years, according to groundwater modeling performed during this FS. Similar to Alternative 3, a combination of IX resin and GAC media would be used to treat the extracted water and four injection wells would be used to recharge the treated water to the aquifer. This alternative also includes long-term groundwater monitoring and institutional controls.

- Alternative 5 - Additional Alternative A. Alternative 5 includes a total of five extraction wells (including the two existing groundwater RRA extraction wells) located along the plume axis and pumping at a combined flow rate of 906 gpm. This alternative would be expected to achieve regulatory or risk-based standards for the COCs in approximately 14 years, according to groundwater modeling performed during this FS. Similar to Alternative 3, a combination of IX resin and GAC media would be used to treat the extracted water and four injection wells would be used to recharge the treated water to the aquifer. This alternative also includes long-term groundwater monitoring and institutional controls.

- Alternative 6 - Additional Alternative B. Alternative 6 includes a total of six extraction wells (including the two existing groundwater RRA extraction wells) located along the plume axis and pumping at a combined flow rate of 981 gpm. Alternative 6 provides an alternative designed to achieve background concentrations for the COCs in approximately 17 years, according to groundwater modeling performed during this FS. Similar to Alternative 3, a combination of IX resin and GAC media would be used to treat the extracted water and four injection wells would be used to recharge the treated water to the aquifer. This alternative also includes long-term groundwater monitoring and institutional controls.

Each of these remedial alternatives was evaluated in detail according to the threshold and primary balancing criteria identified below. The modifying criteria identified below will be assessed based upon input on this Revised Draft FS Report.

Category	Criteria
Threshold	Overall protection of human health and the environment
	Compliance with regulations
Primary Balancing	Long-term effectiveness and permanence
	Reduction of toxicity, mobility, and volume through treatment
	Short-term effectiveness
	Implementability
	Cost
Modifying	State Acceptance
	Community Acceptance

Following the detailed analysis, the six comprehensive remedial alternatives were compared. The comparison highlighted the relative advantages and disadvantages of the alternatives with respect to the seven threshold and primary balancing criteria. A summary of the comparative analysis follows.

Alternatives 3 through 6 all have the potential to protect human health and the environment and restore the aquifer, but vary in the time required to achieve these objectives. Alternative 1 provides no active remediation. Alternative 2 would protect human health and the environment, but would not restore the aquifer as quickly as the other alternatives. Alternative 4 is predicted to remediate the aquifer to risk-based levels most quickly (estimated 10 years). Alternative 3 is predicted to achieve background in less than 30 years. Alternatives 5 and 6 are predicted to reach risk-based and background levels in 14 and 17 years, respectively, according to model predictions. Alternative 1 would not meet the remedial action objectives.

The long-term effectiveness and permanence of the alternatives are similar, but as indicated above, the time to reduce COCs to background concentrations, would be obtained most quickly by Alternative 6. Alternative 3 would reach risk-based concentrations most quickly. All alternatives, except the minimal action alternative, would reduce the toxicity, mobility, and volume of contaminated groundwater through similar treatment. However, Alternatives 3 through 6 would be most effective at actively reducing toxicity, mobility and volume. Alternative 1 would not actively reduce the toxicity, mobility and volume.

The short-term effectiveness criterion considers the ability of the alternative to protect the community and on-site workers during implementation of the remedy and the impact to the environment as a result of the action. Alternative 4 would have the least short-term impact in terms of impact to community and on-site workers because the remedy would be complete in 10 years. Alternatives 1 and 2 would have the least environmental impact based on vegetation clearance followed by Alternatives 3, 5, 4, and 6.

All six alternatives can be implemented. Alternative 1 is the easiest to implement followed by Alternatives 2, 5, 3, 4, and 6. The estimated costs of the Alternatives are presented below:

Alternative	Estimated Costs		
	Capital	**Present Worth of O&M**	**Total Present Worth**
1	$ 1,550,000	$ 1,300,000	$ 2,850,000
2	$ 3,640,000	$ 11,400,000	$ 15,000,000
3	$ 5,620,000	$ 14,700,000	$ 20,300,000
4	$ 10,200,000	$ 15,500,000	$ 25,700,000
5	$ 8,340,000	$ 12,700,000	$ 21,000,000
6	$ 9,860,000	$ 16,700,000	$ 26,600,000

Alternative 1 provides the lowest cost because it is a minimal action scenario, involving long-term groundwater monitoring and institutional controls. Alternative 2 provides the next lowest cost, in part because this alternative uses the existing extraction wells and piping of the groundwater RRA ETR system. The total present worth cost of Alternatives 3 and 5 are similar, and Alternatives 4 and 6 are higher due to additional flow rate, extraction wells and/or pumping duration to reduce COCs to background concentrations. The following table summarizes the main features of each alternative under consideration in the Revised Draft FS.

Alternative	Concentration Objectives	Number of Extraction Wells	Total Extraction Rate	Years to Achieve RBC*	Years to Achieve Background**	Estimated Cost (millions)
1	-	0	0	-	-	$ 2.9
2	-	2	320	-	>50	$ 15.0
3	Background	4	472	-	27	$ 20.3
4	Risk-based	5	1417	11	-	$ 25.7
5	Risk-based	5	906	14	15/20+	$ 21.0
6	Background	6	981	-	15/17+	$ 26.6

*Years to achieve risk-based concentration for most recalcitrant COC modeled.
**Years to achieve background concentration for most recalcitrant COC modeled.
+upgradient/downgradient of Pew Road

The next steps to select a comprehensive remedy for the Demo 1 Groundwater Operable Unit are the preparation of the Final FS Report and the Draft Remedy Selection Plan, which are scheduled for submission on 08/23/04 and 09/21/04, respectively. The Final FS Report will incorporate comments from EPA, DEP and the public. The Draft Remedy Selection Plan will document the proposed remedial action alternative. The plan will summarize the description, analysis and comparison of all alternatives evaluated in the FS and describes the rationale for selecting the proposed remedial alternative.

1.0 INTRODUCTION

This Revised Draft Feasibility Study (FS) presents the evaluation of comprehensive remedial alternatives to remediate explosives and perchlorate contamination in groundwater at Demolition Area 1 (Demo 1) at Camp Edwards (Figure 1-1), pursuant to United States Environmental Protection Agency (EPA) Administrative Orders Safe Drinking Water Act (SDWA) I-97-1019 (AO1) and 1-2000-0014 (AO3).

The Massachusetts Military Reservation (MMR) consists of approximately 21,000 acres. The Department of the Army holds the lease from the Commonwealth of Massachusetts and has licensed the 14,500 acres comprising Camp Edwards to the Massachusetts Army National Guard (MAARNG). The U.S. Army/National Guard Bureau's Impact Area Groundwater Study Program (IAGWSP) has been performing soil and groundwater investigations under the Groundwater Program at Camp Edwards since 1997 pursuant to AO1, as amended July 17, 1998. These investigations were undertaken to determine if military training had impacted the sole source aquifer that underlies Camp Edwards. EPA subsequently issued SDWA Administrative Order 1-97-1030 (AO2), which prohibited “all planned detonation of ordnance or explosives at or near the Training Ranges and Impact Area except for UXO activities”.

A third EPA Administrative Order 1-2000-0014 (AO3) dated 01/07/00 required the IAGWSP to implement rapid response actions (RRAs) and remedial actions to address contamination that presents a potential threat to the sole source aquifer. The rapid response actions required specifically required by AO3 addressed elevated concentrations of contaminants in soil and have been completed. The remedial action component of AO3 requires that a FS, Remedial Design (RD) and Remedial Action (RA) be completed for Areas of Concern (AOCs), one of which is Demo 1. This FS for the Demo 1 Groundwater Operable Unit (OU) has been prepared based on data presented in the Final Demo 1 Groundwater Report Addendum (AMEC, 2004a), submitted on 04/28/04.

1.1 Purpose of FS Report

Per AO3 (Appendix B, Section 1, I, A), the objectives of the FS are to:

1. Review the applicability of various remedial technologies, including innovative technologies, to determine whether they are appropriate and technically implementable remedies;

2. Identify the Remedial Action Objectives;

3. Determine if each alternative developed by combining applicable technologies is effective, by evaluating in the short and long term whether it is:

    (a) effective,
    (b) implementable, and
    (c) cost effective.

4. Evaluate each of the effective remedial alternatives or combination of alternatives through a detailed and comparative analysis.

The FS also includes, but is not limited to, conceptual design elements, engineering analyses, cost analyses, and an analysis of time frames for the achievement of specific clean-up goals.

1.2 Organization of Report

Section 2 includes a discussion of the site description and history, prior investigations, including the Contaminant of Concern (COC) identification process described in Technical Memorandum (TM) 01-2 (AMEC, 2004a), and additional work being conducted or proposed for Demo 1. Section 3 identifies the site geology, including surficial and bedrock geology, site hydrogeology, including a description of hydraulic gradients, flow rates, and flow directions, pneumatic slug testing, additional groundwater investigation results, contaminant fate and transport, and contaminant nature and extent. Section 4 presents the screening discussion for the technology process options under consideration. Section 5 documents the identification and development of comprehensive remedial action alternatives. Section 6 provides a detailed evaluation of each alternative. Section 7 provides a comparative analysis of alternatives. Section 8 summarizes the conclusions of the study. Section 9 provides references for the document.

2.0 SITE BACKGROUND

Historical site operations, site background, regulatory history, and site investigations conducted at Demo 1 are summarized in this section. Figure 2-1 presents the Demo 1 topographic depression where historical site demolition activities were conducted.

2.1 Site Description and History

Demo 1 is located north of Pocasset Forestdale Road and south of the Impact Area at MMR (Figure 1-1), west of Turpentine Road and east of Frank Perkins Road. Demo 1 is a kettle hole (a depression resulting from the melting of a remnant glacial ice block covered with stratified drift) that covers approximately one acre at its base, 45 feet (ft) below the surrounding grade. A perimeter access road surrounds the entire topographic low and associated sloping sidewalls for a total area of approximately 7.4 acres (Figure 2-1). The bottom of the kettle hole is nearly flat and cratered. During average hydrologic conditions, the lowest areas and individual craters remain wet for most of the winter and spring. In recent years during drought conditions, the bottom of the kettle hole has been almost completely dry. The depth to groundwater from the base of the depression has varied from 45 to 48 ft since water level measurements began in 1999. A concrete observation bunker once existed on the north-facing slope of the south sidewall but has been removed. Demolition and disposal activities appear to have occurred primarily in the topographic low, based on historic maps and interview information. According to some interviews, demolition activities resulted in the intermittent ejection, or “kick out”, of explosives and/or demolition materials from the base of the depression into the surrounding area.

Table 2-1 depicts the type of munitions used as donor charges for demolition activities at Demo 1 and the explosive mixtures and quantities for each. Table 2-1 indicates that the predominant explosive used in demolition munitions is hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX). followed by 2,4,6-trinitrotoluene (TNT). Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) is not used in any of the demolition munitions. HMX is an impurity in the manufacturing process of RDX. It can be present with RDX at up to ten percent of the total RDX mass. Soil and groundwater quality data reflect the higher percentage of RDX versus HMX in the demolition munitions. HMX is also a constituent of some explosive fillers used in munitions that may have been detonated or disposed at Demo 1. Waste material from the contractor activities at the J Ranges that contained HMX was reportedly disposed of at Demo 1.

Soil and groundwater samples were not initially analyzed for perchlorate. However, in August 2000 groundwater samples were submitted for perchlorate analysis. Following detections in several Demo 1 groundwater samples, soil samples collected after November 2001 were submitted for perchlorate analysis.

Additional details regarding the site history are available in the Final TM 01-2 Demo 1 Groundwater Report (AMEC, 2001a), in the RRA Plan (AMEC, 2003b), and in the Demo 1 Groundwater Report Addendum to Technical Memorandum TM 01-2 (AMEC, 2004a).

2.2 Site Geology

The geology of western Cape Cod comprises glacial sediments deposited during the retreat of the Wisconsin stage of glaciation. Three extensive sedimentary units dominate the regional geology: the Buzzards Bay Moraine (BBM), the Sandwich Moraine (SM), and the Mashpee Pitted Plain (MPP). The BBM and the SM lie along the western and northern edges of western Cape Cod, respectively. The BBM and SM are composed of ablation till, which is unsorted material ranging from clay to boulder size, which was deposited at the leading edge of two lobes of the Wisconsinian glacier at its furthest advance. These moraines form hummocky ridges. The MPP, which consists of fine- to coarse-grained sands forming a broad outwash plain, lies south and east of the two moraines. Underlying the MPP are fine-grained, glaciolacustrine sediments and basal till at the base of the unconsolidated sediments. The Demo 1 depression is located within the MPP (Figure 2-2). The Demo 1 plume originates in the MPP, eventually flowing into the BBM.

The lithologic data beneath the Demo 1 kettle hole suggests increased clay content near the ground surface, which may contribute to ponding of surface runoff. The drilling logs for these borings indicate that clay and sand is present in the top 7 to 10 ft, which then changes to mostly sand below 10 ft. This is consistent with the visual observation of ponded water in the Demo 1 area during the wetter winter months. Beneath the Demo 1 depression, a layer of till (5 to 20 ft thick) is present on top of bedrock (see Figure 2-8 for cross-section representation). The top of bedrock is approximately -200 ft NGVD (National Geodetic Vertical Datum), about 300 ft below the bottom of the Demo 1 depression and is approximately 325 ft below the general land surface just west of the Demo 1 depression. Further west at Pew Road, both the ground surface elevation and bedrock elevation are higher and the top of bedrock is approximately –130 ft NGVD or about 330 ft below ground surface. Along the power line, at monitoring well MW-258, bedrock is at approximately the same elevation, -130 ft NGVD, however the land surface elevation drops and the depth to the top of bedrock is about 220 ft below ground surface.

In the area east of Frank Perkins Road, subsurface lithology is dominated by varying compositions of fine, medium and coarse sand with occasional gravels. As identified by Masterson et al. 1996, the MPP exhibits a coarsening upward sequence resulting from progradation of lacustrine, bottomset, foreset, and topset sedimentary facies, consistent with a glacial depositional environment. Ground surface elevation in the MPP portion of the Demo 1 plume is relatively flat from the western edge of the kettle hole depression to the eastern edge of the moraine.

West of Frank Perkins Road, the Demo 1 plume crosses into the BBM. As expected, the BBM is comprised of fine to coarse sand and gravel, with discontinuous and continuous clays and silts. West and downgradient of Frank Perkins Road the ground surface rises approximately 55 ft from MW-165 in the MPP to MW-211 in the BBM. Likewise, the top of bedrock surface rises from an elevation of –190 ft NGVD in the Demo 1 depression area to –130 ft NGVD at MW-211, MW-231, and MW-258 in the BBM (see Figure 2-8 for cross-section representation).

2.3 Site Hydrogeology

A single groundwater flow system underlies western Cape Cod, including MMR. The aquifer system is unconfined (i.e., the water table is in equilibrium with atmospheric pressure and is recharged by infiltration from precipitation). Surface water runoff at MMR is minimal except on extreme slopes, due to the highly permeable nature of the sands and gravels underlying the area. The high point of the water table occurs as a groundwater mound beneath the southeastern portion of Camp Edwards (east of Demo 1 – see Figure 2-3). Groundwater flow generally radiates outward from this mound.

The ocean bounds the aquifer on three sides, with groundwater discharging into Nantucket Sound on the south, Buzzards Bay on the west, and Cape Cod Bay on the north. The Bass River in Yarmouth forms the eastern lateral aquifer boundary.

Surface water is present at MMR in a few of the drainage swales and as ponds in kettle holes in the MPP. The kettle-hole ponds are land-surface depressions that extend below the water table. Where these kettle holes do not extend down to the water table, they are merely surface depressions, such as the Demo 1 depression. On a regional scale, these kettle-hole ponds influence groundwater flow in a similar manner to large aquifer heterogeneity. The larger or deeper the pond, the greater is the effect on slope and direction of the regional water table near the pond. While horizontal groundwater flow is dominant in the aquifer system, vertical flow is important in areas near ponds and at some areas with the SM. Opening Pond, located immediately north of the Demo 1 plume and approximately 2,500 feet west of the Demo 1 depression, is a kettle-hole pond (Figures 2-4 and 2-5).

In the Demo 1 depression, the depth to water is approximately 46 to 48 ft bgs. In other areas of the Demo 1 plume, the depth to water ranges from approximately 43 to 165 ft bgs. The depth to groundwater, therefore, ranges by 122 ft. In contrast, the range in groundwater elevation is almost 14 ft, from elevation 64 ft NGVD in the source area to elevation 50.5 ft at the toe of the plume (Figure 2-3) – a distance of 9,200 feet. This disparity between the wide ranges in depth to water vs. groundwater elevation is due to the presence of rugged, hilly terrain (BBM) in a very permeable sandy aquifer in which water levels tend to flatten out.

Groundwater flow in the Demo 1 area is from north-northeast to south-southwest away from the groundwater mound to the north-northeast and toward the Bourne area to the south-southwest. The horizontal groundwater gradient is approximately 0.0007 ft/ft between the depression area and Frank Perkins Road. Downgradient from Frank Perkins Road, in the BBM, the horizontal gradient increases to 0.0012 ft/ft on the East Side of the moraine, to 0.0023 ft/ft at the downgradient toe of the plume toward the middle of the moraine (Figure 2-5).

Based on past water-level measurements, an average downward vertical gradient of 0.0019 ft/ft has been present between monitoring wells MW-19S and MW-19D in the Demo 1 depression. This has likely been due to localized recharge of precipitation that collects in the bottom of the Demo 1 depression. A distinct vertical gradient is not distinguishable at wells immediately downgradient of MW-19, indicating relatively horizontal flow. At monitoring wells located on and west of Pew Road, between Estey and Pocasset Forestdale Roads, but excluding the power line wells (which are MW-248, MW-252, and MW-258), nine rounds of groundwater elevation measurements have been collected to date. Based on these data, vertical gradients near the toe of the plume become evident. Approximately 2,500 feet downgradient of Frank Perkins Road, downward vertical gradients are observed at every well along Pew Road. The average downward gradient is approximately 0.006 ft/ft. Downward gradients may be the result of a localized lower permeability layer that inhibits downward flow causing a localized build-up of head above it, increasing the head difference across the layer thereby creating downward gradients. Approximately 1,100 feet downgradient of Pew Road, a significant upward gradient of approximately 0.02 ft/ft is observed at wells MW-231 and MW-225. These upward gradients may be the result of a thinner overall saturated thickness, as the bedrock appears to rise to a higher elevation in this area, or due to natural upward gradients as groundwater approaches the discharge location of the aquifer system. At the downgradient edge of the plume along the power line, one round of groundwater elevation measurements has been collected from MW-248, MW-252, and MW-258. From these preliminary data, downward gradients were again observed along the power line. The average downward gradient is approximately 0.002 ft/ft.

Although downward gradients are evident across the lower permeability units in the downgradient area, it appears that groundwater flow above the lower permeability unit is horizontal. The current Conceptual Site Model suggests the presence of a low-angle, low permeability unit that is refracting flow within it and retarding perchlorate migration at depth (see clay unit at MW-211 and MW-225, depicted in Figure 2-13). For this reason, perchlorate has not been observed below the clay unit in the downgradient areas.

The significance of these gradient observations relative to contaminant distribution will be discussed in relation to the Conceptual Site Model, presented in Section 3.0.

Masterson et al. (1996) indicated the hydraulic conductivity of the outwash materials is assumed to range from 125 to 350 ft/day. The ratio of the horizontal to vertical hydraulic conductivity (anisotropy) is estimated at a ratio of 3:1. In addition, Masterson indicated that the hydraulic conductivity of the morainal material has a range of 30 to 150 ft /day. Anisotropy is higher in the moraine than in the outwash. The results of the Central Impact Area 72-hour pumping test indicated a hydraulic conductivity of the outwash of at least 150 ft/day (AMEC, 2002d).

Analysis of historical groundwater elevation data indicates that ambient groundwater elevations were dropping consistently in the Demo 1 area from the start of measurements in 1998 to December of 2002. Observation well data indicates a drop of over 7-ft during that period. Initial review of rainfall data indicates that 1998 was a very wet year compared to the subsequent drought period (1999-2002). Therefore, groundwater elevation data over the four-year drought period showed a significant drop from the high water of 1998. Measurements collected since January 2003 indicated that the water level in Demo 1 has risen up to 2 ft since the low water period ended in December 2002.

2.4 Summary of Investigations and Reports

For administrative purposes, soil and groundwater were divided into separate OUs at Demo 1 for completing additional characterization and FS reports. After this separation, a Final Technical Team Memorandum 01-2, Demo 1 Groundwater Report (AMEC, 2001a) was prepared to characterize groundwater and identify COCs. Similar information for the Soil OU was presented in the Draft IAGWSP Technical Team Memorandum 01-10, Demo 1 Soil Report (AMEC, 2001b).

The following subsections summarize the prior investigations conducted at Demo 1. The Final TM 01-2 Demo 1 Groundwater Report (AMEC, 2001a) and the RRA Plan (AMEC, 2003b) provide additional details regarding prior investigations. The focus of this FS is on groundwater; however soil investigations are also summarized for the reader. This FS does not discuss soil sampling locations at Demo 1 in detail. Additional information on soil investigations and results may be found in the references provided. The locations of groundwater monitoring wells at Demo 1 are presented in Figure 2-4.

2.4.1 Phase I – Impact Area Groundwater Study

Demo 1 was sampled during Phase I of the IAGWSP (1997-98) with a total of six surface soil grids. One boring was completed as a monitoring well nest, MW-19 (Figure 2-4).

Additional details on the sampling, analytical methodology and the associated findings are described in the Draft Completion of Work Report (Ogden, 1998a).

2.4.2 Immediate Response Plan

Based on the initial Phase I groundwater results, an Immediate Response Plan was developed for Demo 1 (Ogden, 1998b). This plan included additional sampling of the wells at MW-19; groundwater profiling at downgradient monitoring well locations MW-31, MW-32, and MW-33; the installation and sampling of nested wells at MW-31, MW-32, and MW-33, and the validation of MW-19 groundwater profile samples using Photo Diode Array (PDA) spectra. Results from the Immediate Response Plan sampling and analysis are documented in the Workplan for Completion of Phase I (Ogden, 1998c).

2.4.3 Workplan for Completion of Phase I

The Workplan for Completion of Phase I (Ogden, 1998c) specified additional soil and groundwater investigations at Demo 1. This plan included the installation of nine borings to a depth of 16 ft, for the collection of soil samples at 1-ft intervals. Each sample was analyzed for explosives using EPA SW846 Method 8330. Based on the locations and the vertical extent of explosives detected in the upper 16 ft, four of the borings were extended to the water table and sampled for explosives at 2-ft intervals. The Final Technical Memorandum 99-2, Deep Soil Sampling of Demolition Area 1 (Ogden, 2000a) describes these results. One of the borings extended to the water table (Boring B-9) and was converted to a water table monitoring well (MW-73; see Figure 2-4).

The monitoring wells proposed at locations MW-34, MW-35, and MW-36 were installed between locations MW-31 and MW-32/33. The purpose of these additional wells was to locate the downgradient extent of explosive contamination (Figure 2-4). The Response Plan for Demo Area 1 (Ogden, 1999a) describes the results of these groundwater investigations.

2.4.4 Response Plan

Pursuant to the Response Plan (Ogden, 1999a), 14 soil grids were established on the sloped sides of the topographic depression, outside the depression within the perimeter road, and along the outside of the perimeter road.

In addition to the surface soil sampling, the IAGWSP conducted a 100% reconnaissance of the ground surface within, and 50 ft beyond, the perimeter road to look for residual C4 or other bulk explosives. Upon identifying residual C4, smoke grenades, or other explosive residuals, the item was removed in accordance with approved procedures and the location was staked for later soil sampling. Although several pieces of C4 were removed from Demo 1, additional pieces that are not discernible to the naked eye may remain in surface soil at Demo 1. Soil sampling conducted beneath C4 typically detected elevated concentrations of explosives.

The Response Plan (Ogden, 1999a) groundwater investigation consisted of groundwater profiling and installation of monitoring wells upgradient and downgradient from MW-19. A total of six monitoring well triplets were installed. Well locations MW-74 through MW-78 (Figure 2-4) were established along a transect perpendicular to the plume, approximately 1,400 ft downgradient of the source area represented by MW-19. A total of 15 wells were installed at these five locations to delineate the lateral and vertical extent of explosives in groundwater. Three wells were also installed at MW-79, east of the source area, to evaluate upgradient groundwater quality.

Soil borings were advanced and groundwater profiling was conducted at 10-ft intervals starting 4 ft below water table (bwt) and continuing to 94 ft bwt at locations MW-74 through MW-78, whereas profiling was conducted to a depth of 100 ft bwt at upgradient location MW-79. The profile samples were analyzed for explosives via EPA Method 8330 and all initial detects were confirmed or rejected based on a review of the PDA spectral data. Three well screens were placed at each location based on the profile data.

Borings and wells were completed pursuant to the Final Field Sampling Plan (FSP) for Phase II(a) Drilling to Investigate RDX Exceedances (Ogden, 1999b), except that profile samples were submitted for analysis of explosives only and did not include volatile organic compound (VOC) analysis.

After development, the Response Plan monitoring wells (MW-74 through 79) were each sampled for three rounds and analyzed for explosives via EPA Method 8330. All groundwater sampling complied with the Final Groundwater FSP (Ogden, 1997) and the Final FSP for Phase II(a) Drilling to Investigate RDX Exceedances (Ogden, 1999b).

2.4.5 Immediate Response Action

RDX was detected in soil beneath pieces of C4 at three Demo 1 locations at concentrations in excess of the Massachusetts Contingency Plan (MCP) Reportable Concentration for a category S1 soil (RCS-1) of 100 milligrams per kilogram (mg/kg). The IAGWSP submitted an Immediate Response Action (IRA) Plan on 04/19/00 (MAARNG, 2000) in accordance with the MCP section 310 CMR 40.0424 and AO3 to address RDX contamination detected in soil at Demo 1. IRAs are an assessment and/or remedial action undertaken in an expeditious manner to address sudden releases, Imminent Hazards, and/or other time-critical release or site conditions in order to eliminate, abate, or mitigate site conditions which may impact human health, safety, public welfare, or the environment.

On 05/24/00, approximately 1 cubic ft of soil was excavated from the three locations using hand tools, placed in a 55-gallon steel drum, and transported to the temporary waste storage area on MMR. The soil excavated under the IRA at Demo 1 was treated in conjunction with RRA soil in accordance with the requirements of AO3. A grab sample was collected from the base of each soil removal area to assess the effectiveness of the IRA. RDX levels in the three grab samples were below the MCP Reportable Concentration of 100 mg/kg.

The IAGWSP submitted an IRA Completion Report documenting the successful completion of the IRA Plan under the MCP on 01/08/01 (IAGWSP, 2001).

2.4.6 Phase I Munitions Survey Project

Subsurface geophysical investigations conducted in the entire 7.4-acre depression of Demo 1, during March and April of 2000 (Tetra Tech, 2000) used both electromagnetic and magnetometer instruments. The investigation detected over 2,500 anomalies and 25 of these anomalies were selected for validation. Trained explosive ordnance technicians used hand tools and a mini-excavator to expose the 25 anomalies with the highest signal amplitudes. During excavation, many of the potential targets contained more than one type of metal object, with each object contributing to the overall geophysical signal. In most cases, the excavated pits contained metal debris, including razor wire, metal railroad rails and metallic mesh. The following ordnance items were excavated: two 750-pound practice bombs, nine 3.5-inch practice rockets, three 75 millimeter (mm) practice projectiles, one 175 mm (7-inch) projectile, and one 155 mm practice projectile. Uniformed military Explosive Ordnance Disposal (EOD) technicians determined that the 175 mm projectile contained high explosives (Tetra Tech, 2000).

At one of the anomaly locations a layer of discolored, possibly burned soil was discovered. Two spent 20 mm practice rounds, spent 30 mm rounds, three smoke flares, and one 20 mm round with full ballistic tip were identified within the “burn pit”. The excavation activities were terminated at that time to allow further planning before additional characterization of the discolored material, which is described in Section 2.4.8, Supplemental Soil Investigations.

2.4.7 Feasibility Study Work Plan

A Final Feasibility Study Work Plan (FSWP) (AMEC, 2000a) was prepared in accordance with AO3 under the SDWA. The FSWP addresses five AOCs identified in AO3, including Demo 1. The objective of the FSWP was to provide the foundation, approach, and schedule for subsequent submittals required to complete the FS, RD, and RA for the AOCs. The FSWP indicated that Demo 1 would be subdivided into a groundwater OU and a soil OU. This would allow the two media to be evaluated on separate timelines, thereby expediting the remedy selection process.

The Demo 1 FSP of the FSWP (AMEC, 2000a) described additional deep soil sampling at Demo 1. This work was recommended in the Technical Memorandum 99-2, Deep Soil Sampling of Demolition Area 1 (Ogden, 2000a) and completed in order to further characterize the unsaturated zone at the base of the topographic depression.

The FSWP also recommended that additional characterization of the downgradient extent of the contamination be completed. A monitoring well nest was installed and sampled at location MW-114 (Figure 2-4) to characterize groundwater at the downgradient edge of the plume. Based upon the levels of RDX detected at location MW-114, monitoring wells were installed at two additional locations (MW-129 and MW-139) to provide further delineation to the south and west. Low concentrations of RDX in groundwater at monitoring well location MW-129 prompted the installation of additional monitoring wells at locations MW-162 and MW-165 (Figure 2-4). The elevated concentration of RDX detected at monitoring well location MW-165 prompted the planning for three additional monitoring well clusters along Pew Road, between Estey and Pocasset Forestdale Roads. Monitoring wells were completed at locations MW-173, MW-175, and MW-186, based on the United States Geological Survey (USGS) characterization of regional groundwater flow direction at that time.

2.4.8 Supplemental Soil Investigations

Supplemental Soil Investigations for Demo 1 (Ogden, 2000b) were proposed to address the “burn pit” identified as part of the Munitions Survey Project (Tetra Tech, 2000), extension of the additional deep soil borings, and further surface soil characterization requested by the EPA. These supplemental investigations were conducted in October 2000.

The supplemental soil investigations included 15 surface soil samples and eight soil samples collected from two test trenches excavated through the “burn pit”. The “burn pit” was identified as a result of the excavation of identified geophysical anomalies at Demo 1 (Tetra Tech, 2000). Anomaly location 5 was investigated in detail after discovering a layer of black discolored, possibly burned sandy soil 7 ft below ground surface (bgs). The area of burned material is approximately 9 ft by 10 ft in length with an average thickness of 2 ft and the bottom depth is 7.5 ft bgs. Three soil samples were collected to characterize the stained/burned soils and five soil samples were collected beneath and adjacent to the stained/burned material. The Demo 1 Soil RRA/RAM Plan (AMEC, 2003b) presents the details of the soil analytical parameters tested on Demo 1 soils to date and soil analytical results.

2.4.9 Additional Geophysical Anomaly Investigation

During Phase I of the Munitions Survey Project, the 25 electromagnetic (EM) anomalies in Demo 1 that had the highest sensor readings (greater than 400 millivolts (mV)) were excavated and identified, as discussed in Section 2.4.6. Between July 16 and July 26, 2001, 19 anomalies having the next highest signals (between 300 and 399 mV) were excavated and identified (Tetra Tech, 2001). During the investigation of anomalies, burnt debris and/or ash were encountered. As a result, samples were collected at each anomaly location where ash, UXO, UXORM, stained soil, and/or unusual odors were encountered. The sampling protocol is described in the Tetra Tech Geophysical Investigation Report (Tetra Tech, 2001). The majority of material recovered consisted of metal scrap, concertina wire, steel I-beams, steel plates and miscellaneous metal items. All of the UXO and UXORM items recovered were either expended or were training rounds containing no explosives. At the five anomaly locations containing ash (locations 26, 27, 33, 36 and 44), burnt-out small arms cartridge casings (5.56 mm, 7.62 mm, and 50 caliber), pyrotechnics, fuses, thermal batteries, rocket bodies and larger projectile casings were recovered. A black viscous substance with a diesel fuel-like odor was encountered and sampled at anomaly location 44 at 10 to 13 ft bgs (Tetra Tech, 2001).

2.4.10 Additional Soil Sampling

A proposed soil sampling plan was submitted to EPA and DEP on June 8, 2001, on behalf of the IAGWSP (AMEC, 2001b). The original proposal addressed the collection of samples for Total Organic Carbon (TOC) analysis and the revised plan included analyses for Volatile Organic Compounds (VOCs), Semi-volatile Organic Compounds (SVOCs), metals and a contingency for dioxins/furans as requested by EPA.

Three additional soil borings (B-26, B-27 and B-28) were advanced within the depression at Demo 1 between August 8 and August 10, 2001. Soil borings B-26 and B-28 were advanced to 12 ft bgs and soil boring B-27 was advanced to 40 ft bgs. Samples were collected and analyzed for VOCs, SVOCs, metals, and TOC.

The Technical Team Memorandum 01-10, Draft Final Demo 1 Soil Report (AMEC, 2001c) presents the results of these investigations.

2.4.11 Demo 1 Groundwater Report

The TM 01-2 Demo 1 Groundwater Report (AMEC, 2001a) characterized the extent of the contaminant plume as it was understood at the time, evaluated the degradation of TNT within the plume, evaluated the sporadic presence of VOCs, and identified laboratory artifacts in groundwater samples. To focus the contaminant fate and transport discussions, the Groundwater Report (AMEC, 2001a) established COCs for groundwater at Demo 1 in accordance with the Draft Final COC Identification Process (Ogden, 2000c).

Section 3.0 of this report describes the current extent of the COC plume, degradation within the plume, and presence of non-COC compounds in groundwater. The following discussion summarizes the COC identification process from TM 01-2.

The COC Identification Process for groundwater at Demo 1 involved a detailed evaluation of all detected compounds in a step-wise approach. First, the groundwater analytical data (as of March 2001) were summarized and then all detected compounds were screened against risk-based concentrations (EPA Region IX tap water preliminary remediation goals). Next, the retained compounds or contaminants of potential concern (COPCs – i.e., those that exceeded the screening levels) were further assessed in a screening Risk Evaluation to identify initial COCs. The compounds that presented unacceptable risk to human health in the screening Risk Evaluation were evaluated in a Risk Management step that included consideration of background concentrations, frequency of detection, laboratory and sampling artifacts, the status of compounds as essential nutrients, and other factors.

The results of the COPC screening, Risk Evaluation and Risk Management process (AMEC, 2001a) identified the following six compounds as COCs for the Demo 1 Groundwater OU:

- RDX,
- TNT,
- HMX,
- 4A-DNT,
- 2A-DNT, and
- 2,4-DNT.

In addition to these compounds, perchlorate has been retained as the seventh COC for the Demo 1 Groundwater Operable Unit. Perchlorate, for which groundwater was not analyzed prior to August 2000, has been repeatedly detected in groundwater at Demo 1. Table 2-2 presents the COC results by monitoring well at Demo 1.

The chlorinated solvent tetrachloroethylene (PCE) has been detected at low estimated concentrations (less than 1 μg/L) in monitoring wells along the centerline of the RDX plume at Demo 1. PCE was not identified as a COC, however it will continue to be monitored annually at four well locations in the Long Term Groundwater Monitoring (LTGM) program. The treatment technologies being proposed for the explosive compounds would also address organic contaminants such as PCE.

Table 2-2 presents a summary of groundwater analytical detections at Demo 1. This table includes the frequency of detection, maximum concentrations, and mean concentration for each analyte detected. There are no new, elevated detections of compounds in groundwater that necessitate an updated risk evaluation. The risk characterization provided in TM 01-2 is conservative and protective of human health and the environment.

2.4.12 Demo 1 Groundwater Draft FS Report

The Draft FS Report (AMEC, 2001d) presented a detailed assessment of the nature and extent of contamination in groundwater at Demo 1 at the time of its production in September 2001. This report also evaluated several remedial alternatives, based on the contaminant extent as it was known at that time. A Conceptual Site Model, which ties together the understanding of the source of COCs as well as dominant fate and transport characteristics, is presented in Section 3.0.

2.4.13 Post-Screening Investigation

The objective of the Post-Screening Investigation (PSI) for the Demo 1 Soil OU was to provide data necessary to confirm the nature and extent of soil contamination at Demo 1 and complete the FS for the soil OU. The following activities were conducted based on discussions with the EPA and DEP.

- Composite grid samples were collected from 21 locations, not associated with geophysical anomalies, outside of the depression (or 120-ft elevation contour) and inside of the perimeter road.

- Composite grid samples were collected from three locations inside the depression and analyzed for polychlorinated naphthalenes (PCNs), dyes, and perchlorate to further refine the extent of contamination within the depression.

- Magnetic anomaly validation was conducted at three locations outside the perimeter road to confirm that the perimeter road represents the appropriate site boundary for Demo 1 and that past activities related to Demo 1 have not adversely impacted areas outside of the perimeter road.

The results and observations from the PSI were incorporated into the RRA/RAM Plan (AMEC, 2003a) and provided the basis for the extent of soil remediation at Demo 1.

2.4.14 Fate and Transport Investigations

The objectives of the Laboratory Fate and Transport Work of High Explosives at MMR (Speitel, 2002) were to provide Camp Edwards specific fate and transport data that could be: 1) incorporated into the current conceptual model for explosives movement through soil and groundwater and 2) utilized for modeling of explosives movement in both the unsaturated and saturated zone at Camp Edwards.

The IAGWSP believes that fate and transport modeling is an integral component of realistically evaluating the fate and transport of contaminants within the saturated and unsaturated zones. The study included a column experiment using soil collected from Camp Edwards and examined four major topics related to contaminant fate and transport in groundwater: dissolution kinetics, biodegradation, sorption, and desorption. The dissolution rates and sorption parameters derived from this investigation were incorporated in the Revised Draft FS groundwater flow and transport model, as appropriate.

2.4.15 Groundwater Report Addendum

Although the Demo 1 Groundwater Report (AMEC, 2001a) was approved by DEP and EPA in April 2001, the DEP issued a letter requesting additional characterization of the groundwater plume in late 2001 (MADEP, 2001). The IAGWSP completed additional groundwater investigations including the installation of 33 new monitoring wells comprising 11 new well clusters, profile sampling for perchlorate and explosives analyses, and continued groundwater sampling and analyses at all Demo 1 wells. The IAGWSP described these investigations and requested concurrence of adequate plume characterization for the purpose of proceeding with the FS at Demo 1 in their 04/18/03 letter to EPA and DEP.

The IAGWSP received written notification that delineation of the Demo 1 groundwater plume was considered complete for the purposes of conducting a FS from EPA on 05/06/03 (USEPA, 2003b) and from DEP on 05/21/03 (MADEP, 2003). The Final Demo 1 Groundwater Report Addendum (AMEC, 2004a) presents the results of the additional investigations conducted from 2001 to April 2003 and updates the previous Conceptual Site Model (AMEC, 2004a). The nature and extent of COCs is described in Section 2.7.

The following text presents the additional plume delineation activities at Demo 1, prior to updating the Conceptual Site Model and the groundwater transport model. For more information, see the Demo 1 Groundwater Report Addendum (AMEC, 2004a).

Figure 2-6 depicts the estimated extent of Demo 1 COCs (perchlorate, RDX, HMX, TNT, 2,4-DNT, 2A-DNT, 4A-DNT) in groundwater based on data available through May 2003. The plume depiction in plan view for each COC is representative of the widest observed concentration at each transect cross-section.

In response to the DEP request for additional characterization at Demo 1 in November 2001, a series of wells were planned in the area between Frank Perkins Road and Pew Road to identify the leading edge of the plume. At that time, significant detections of perchlorate and RDX were identified in MW-165, however, no detectable concentrations were measured at the Pew Road sentry wells (MW-173, MW-175, MW-186). A phased approach was agreed upon whereby one well was proposed (D1P-9 / MW-210) for installation approximately 650 ft west of Frank Perkins Road. Starting with monitoring well location MW-210, groundwater profile samples were analyzed for perchlorate in addition to explosives. Two additional "wing" wells, one to the north (D1C-2) and one to the south (D1C-1) of MW-210, were proposed for installation if sampling at MW-210 revealed no detections of perchlorate or RDX above their relevant standards.

However, should either of the relevant standards agreed to at that time for perchlorate (1.5 μg/L) or RDX (2 μg/L) be exceeded at MW-210, a contingency well location, D1C-3, was planned at a location approximately 650 ft west of MW-210. The additional "wing" wells would then be placed to the north (D1C-5) and to the south (D1C-4) of D1C-3.

Perchlorate was detected in several profile samples at monitoring well location MW-210 in excess of the relevant standard agreed to at that time and a first-time detection of perchlorate was measured at an estimated concentration of 0.63J μg/L (analytical method detection limit [MDL] was reduced from 1.5 to 0.35 μg/L; "J" qualifier denotes an "estimated value" since the result is above the MDL but below the laboratory reporting limit of 1 μg/L for perchlorate) in monitoring well MW-173M3 located on Pew Road. Based on this information, the IAGWSP proposed that an additional monitoring well be installed south of the original Pew Road monitoring wells and that the plans for monitoring wells D1C-1 through D1C-5 be abandoned. Monitoring well location MW-211 was installed, sampled, and found to contain concentrations of perchlorate exceeding the relevant standard agreed to at that time for perchlorate of 1.5 μg/L in early June 2002.

At this time, modified laboratory methods enabled lower detection limits for perchlorate, which increased the number of low-level detections at "boundary" monitoring wells (MW-78, MW-162, MW-74, MW-32, MW-172). To address this evolving data gap, monitoring wells on the southern plume edge (MW-214 and MW-221) were proposed for installation. No detections of perchlorate or RDX were reported for these new boundary wells after the first round of sampling.

Location MW-255 was established west of Opening Pond and east of Frank Perkins Road to define the northern plume boundary in this area. This cluster was located in an area previously assumed to be outside of the plume footprint. However, two estimated detections of perchlorate at 0.68J and 0.81J μg/L were discovered in the profile analytical results. Following this result, an estimated detection in the middle screen of 0.54J μg/L was measured in March 2003, a detection of 1.1 μg/L was measured in July 2003, and a second estimated detection of 0.36 μg/L was measured in December 2003.

Piezometers DP OP01 and DP OP02 at Opening Pond were driven to depths of 40 and 62 ft bwt, respectively. Both were sampled and analyzed for perchlorate and explosives. No detections were measured in these drivepoint locations. A staff gauge (DP SG) was installed in the south end of Opening Pond and will be monitored with the rest of Demo 1 monitoring well locations to ascertain the connection of the Pond to the water table.

Based on the perchlorate concentration (3.0 μg/L) detected in monitoring well MW-211M2, a series of three monitoring well clusters (MW-225, MW-231, MW-240) were installed approximately 1,200 ft west of MW-211 on Pew Road (Figure 2-6). Perchlorate was detected at a concentration of 2.9 μg/L in monitoring well MW-225M3 and at 1.5 μg/L in monitoring well MW-231M2. Subsequent to the detections in these monitoring wells, three additional locations (MW-248, MW-258, MW-252) were established 1,000 ft west of MW-225. Perchlorate was detected in profile samples at the northernmost (MW-258) and southernmost (MW-252) well locations. Analytical results for MW-258 showed low level detects in the uppermost and middle screens (MW-258M3 and MW-258M2) estimated at approximately 0.49J and 0.41J μg/L respectively, for the first sampling round. The first and third sampling round results for MW-248 and MW-252 were non-detect at all well screens. However, a single detection of perchlorate (0.56J μg/L) was discovered during the second monitoring round at MW-252 in the shallowest well setting (MW-252M3).

Using the investigation criteria for perchlorate and RDX, the perchlorate detections at the westernmost transect of wells along the power distribution line (MW-248, MW-252, MW-258) were judged to sufficiently bound the plume extent in the downgradient area (see Figure 2-4).

2.4.16 Pneumatic Slug Testing

Typical well point permeability testing is difficult because the permeability of the aquifer beneath Demo 1 is extremely high. Even with electronic data logging devices, standard mechanical slug testing is typically only possible in aquifers with either low or moderate hydraulic conductivities (less than approximately 50 ft/day). In aquifers with very high hydraulic conductivities, it is difficult to create enough instantaneous change in water level to provide a valid slug test. In addition, because the change in water level is so slight, the mechanical action of moving the slug can displace the pressure transducer in the well to invalidate the subtle changes seen. With a pneumatic slug tester, these limitations can be overcome. Descriptions of pneumatic testing are described in McLane, et. al, 1990 and Levy and Pannell, 1991.

Butler and Garnett (2000) developed a new analysis method for pneumatic slug tests of high permeability aquifers. The method is suitable for wells in partially penetrating unconfined aquifers such as the monitoring wells at MMR. The method utilizes the graphical matching of theoretical type curves to plots of slug test response data.

Pneumatic slug tests were conducted at 28 monitoring wells at 10 Demo 1 well clusters (MW-32, MW-165, MW-175, MW-210, MW-211, MW-221, MW-225, MW-240, MW-248, and MW-252). Table 2-4 presents the estimated hydraulic conductivities associated with each monitoring well tested.

Previous estimates of groundwater velocity at the downgradient edge of the plume ranged from approximately 0.61 to 1.57 ft/day or 223 to 573 ft/year. This estimate was based on a measured gradient of 0.0026 in the region of MW-225 (11/02), an effective porosity of 0.3 and a range of hydraulic conductivity in the toe of the plume area from 70 to 180 ft/day.

Pneumatic slug test results of wells tested within the plume interval indicate a range of hydraulic conductivity from 27 to 195 ft/day. The geometric mean of hydraulic conductivity is approximately 75 ft/day in the Pew Road area, 105 ft/day in the between Pew Road and the Power Line, and 103 ft/day at the Power Line.

2.5 Ongoing and Planned Investigations and Studies

The following subsections summarize ongoing and planned investigations and studies relevant to Demo 1 Groundwater Operable Unit.

2.5.1 Long Term Groundwater Monitoring

Groundwater sampling will continue at Demo 1 in accordance with the Revised Appendix B for the Long-Term Groundwater Monitoring (LTGM) Plan (AMEC, 2004c). The objective of the LTGM Plan is to provide the necessary data to evaluate concentration trends over time and to monitor contaminant migration. The selection of wells and the methods of analysis are based on previous findings. Each new well installed at Camp Edwards is sampled for three rounds prior to being considered for inclusion in the LTGM Plan.

2.5.2 Supplemental Post-Screening Investigations

The objective of the Supplemental PSI sampling was to collect additional data to adequately characterize the lateral extent of soil contamination at Demo 1.

In addition to the previous PSI described in Section 2.4.13, soil sampling was recently completed at 22 soil grids located outside the perimeter road at Demo 1 and two grids located within the perimeter road to delineate the lateral extent of soil contamination at Demo 1. The results of the soil sampling were used to refine the contiguous extent of COCs proposed for remediation. Results of the PSI and Supplemental PSI soil sampling will be summarized in the RRA Soil OU Completion of Work Report.

2.5.3 Innovative Technology Evaluation

The IAGWSP initiated the Innovative Technology Evaluation (ITE) program in March 2000 to identify and investigate promising innovative technologies to remediate soil and groundwater contaminated with explosives at Camp Edwards. This program specifically targeted technologies and vendors that had a measure of demonstrated success remediating explosives. Several groundwater studies are complete and an ITE report

(AMEC, 2001c) presents the results. Initial ITE Treatability Studies for groundwater were completed for the following technologies: in-situ cometabolic reduction; in-situ chemical oxidation (using permanganate); and in-situ chemical oxidation (using Fenton's Reagent). Separate studies have been performed and reported for the ex situ fluidized bed reactor (FBR) technology (AMEC, 2002b and 2002c).

Following the initial evaluations, several treatment processes were evaluated for removal of perchlorate and/or explosives in groundwater at the MMR. The treatment processes include granular activated carbon (standard GAC), GAC that has been tailored with ionic monomers and polymers (tailored GAC), and ion exchange (IX) resins. These studies were performed to assess the ability of various treatment processes to remove perchlorate and explosives from the groundwater at MMR during full scale treatment operations. The studies were performed using groundwater from three locations at MMR:

- Study #1: MW-80M2 (western boundary of MMR). Perchlorate has been detected in concentrations of approximately 1 µg/L.
- Study #1: MW-211M2 (downgradient portion of Demolition Area 1 groundwater plume). Perchlorate was present in concentrations of approximately 6 µg/L. Note that at full scale operations, concentrations are expected to be lower due to an increased capture zone.
- Study #2: PW-1 (Turpentine Road in the Central Impact Area). Perchlorate has been detected in concentrations of approximately 1 µg/L and RDX has been detected in concentrations of approximately 5.5 µg/L.

These laboratory studies demonstrated standard GAC is viable for treatment of low concentrations of perchlorate and explosives. The operational life of standard GAC used to remove 6 µg/L perchlorate from groundwater is estimated at approximately 5 months before change-out is required dependent upon an empty bed contact time (EBCT) of 10 minutes (AMEC, 2003d). If the influent concentration is 1 µg/L, the operational life of standard GAC is estimated at approximately 9 months based on an EBCT of 10 minutes (AMEC, 2004b). Higher concentrations of perchlorate up to 10 µg/L may be treated as well, depending on the EBCT, but the GAC may have a correspondingly lower operational life. If RDX is present up to 5 µg/L the operational life would not be significantly affected. Two reports describe the results for these robust laboratory treatability studies using standard GAC and tailored GAC (AMEC, 2003c and AMEC 2004b).

Further ITE Studies are currently being conducted using groundwater from the Pew Road area of the Demo 1 Groundwater OU. The purpose of these additional studies is to evaluate the performance of tailored GAC media and two types of IX resins using low concentration ranges of perchlorate-impacted groundwater (<6 µg/L). The field studies are scheduled for completion in July 2004 and a Draft Report summarizing the results will be submitted in September 2004.

2.6 Summary of Demo 1 Rapid Response Actions

Rapid Response Actions are currently ongoing for both soil and groundwater at Demo 1. The following subsections summarize these actions.

2.6.1 RRA Plan – Soil Operable Unit

The objective of the RRA Plan for the Demo 1 Soil OU (AMEC, 2003b) is to reduce or eliminate potential risks to human health present at Demo 1 as a result of historic open burn and open detonation (OB/OD), disposal and demolition training activities. The soil RRA will eliminate the continuing source to groundwater contamination at Demo 1 associated with geophysical anomalies and contaminated soil.

The soil RRA Plan includes:

- Removal of all geophysical anomalies within the perimeter road at Demo 1 (approximately 7.4 acres),
- Excavation of approximately 15,000 cubic yards of contaminated soil,
- Off-site disposal of "burn pit" materials and metallic and other debris,
- On-site treatment of the soil (15,000 cubic yards) via thermal treatment to remove COCs from the soil,
- Restoration of the site through reuse of treated soil determined to be acceptable.

Anomaly removal and soil excavation and treatment began in Winter 2004 and will be completed during Summer 2004. Treated soil meeting cleanup goals will be returned to the Demo 1 depression and final site restoration will be completed.

2.6.2 RRA Plan – Groundwater Operable Unit

Based on discussions among the EPA, DEP, and Impact Area Review Team (IART), the IAGWSP developed conceptual options for a RRA to begin remediation of the Demo 1 groundwater plume. The groundwater RRA Plan (AMEC, 2003b) includes extraction and treatment of contaminated groundwater from two areas within the plume: one near Frank Perkins Road and another at Pew Road.

The purpose of the groundwater RRA is to begin removing dissolved contaminant mass in the plume while continuing to evaluate the feasibility of comprehensive remedial actions and determining a comprehensive remedy. The overall objective of the proposed extraction, treatment and recharge (ETR) systems at Frank Perkins Road and Pew Road is to provide hydraulic capture of the majority of the groundwater plume to control further migration and to initiate removal and treatment of dissolved contaminant mass contained within the plume.

The proposed major components of the Frank Perkins Road ETR System include:

- A single extraction well pumping at a rate of approximately 220 gallons per minute (gpm);
- An ex-situ treatment process consisting of GAC media and IX resin to treat perchlorate and explosives; and
- Two injection wells installed laterally north and south of the plume with the screened interval below the plume to return treated water to the aquifer.

The proposed major components of the Pew Road ETR System include:

- A single extraction well pumping at a rate of approximately 100 gpm;
- An ex-situ treatment process consisting of GAC media to remove low levels of perchlorate (explosive contaminants are not currently present in groundwater in the downgradient portion of the plume); and
- A single injection well located to the south of the plume (outside the zone of influence of the extraction well) to return treated water to the aquifer.

Construction of the groundwater RRA ETR Systems began in Fall 2003 and system start-up is planned for September 2004.

2.7 Nature and Extent of COCs

A summary of the nature and extent of COCs for the Demo 1 Groundwater OU follows. The Groundwater Report Addendum (AMEC, 2004a) provides additional detail. A Conceptual Site Model, which ties together the understanding of the source of COCs, nature and extent of contamination, as well as dominant fate and transport characteristics, is presented in Section 3.0 of this Revised Draft FS.

Table 2-2 presents the analytical results for the Demo 1 COCs through April 2004. The analytical results for COCs through May 2003 are represented in a series of figures, as referenced below, which show the plan view extent of RDX, perchlorate, and TNT. These COCs were selected for representation because they were identified as the most representative compounds to use in the transport model during the Revised Draft FS modeling, as agreed with DEP and EPA during the Comment Resolution process for the Draft FS. The compound 2,4-DNT was also selected for use in the transport model at that time. However, given the limited number of detections (only detected in a single monitoring well), sporadic detection (none detected in most recent sampling round) and low concentrations (less than 0.5 μg/L), the transport characteristics and historical presence of this compound were considered before deciding how to model this compound.

The representations included in this report used analytical data as of 05/08/03 to construct plume shells for use in subregional flow and transport modeling for the Revised Draft FS. The plume shells shown in the plans and cross-sections illustrate the Conceptual Site Model and illustrate the latest analytical data, as agreed in the 09/11/03 FS Scoping Meeting.

Figure 2-7 presents the RDX data and plume interpretation. It also shows the orientation of the geologic cross-section views. Figures 2-8 through 2-11 depict geologic cross sections and data for RDX. A longitudinal view (A-A’) of lithology and contaminant distribution as well as several cross-sectional views (B-B’, C-C’, D-D’) provide a three-dimensional interpolation of data collected through analyses of groundwater samples.

Figure 2-12 illustrates perchlorate data and plume interpretation are illustrated on Figure 2-12. Figure 2-13 shows the interpreted cross-section of the plume along the direction of flow for the Demo 1 groundwater plume. (Refer to Figure 2-5 for groundwater elevation contours). Figures 2-14 through 2-19 show orthogonal cross-sectional views of the plume progressively downgradient from the source area (B-B', C-C', D-D', E-E', F-F', G-G').

Figure 2-20 presents the TNT distribution in groundwater in plan view. Figure 2-21 shows a longitudinal view (A-A') of the lithology and TNT contaminant distribution.

The presence of explosive and propellant compounds in groundwater is consistent with the following observations:

- RDX and TNT were the most heavily used explosives at Demo 1;
- HMX is an impurity in RDX;
- 2A-DNT and 4A-DNT are degradation products of TNT;
- 2,4-DNT is a propellant that was disposed at Demo 1;
- Perchlorate is a component of inert munitions, fireworks, rocket propellants and pyrotechnics that were likely disposed at Demo 1; and
- Each of the compounds was detected in soil at Demo 1.

2.7.1 Explosive Compounds

RDX is the most widely distributed explosive compound in groundwater at Demo 1. As indicated in Figure 2-7, the measured RDX plume (concentrations above the analytical reporting limit of 0.25 ug/L) extends approximately 4,600 ft downgradient from the source area. The farthest downgradient measured extent of the RDX plume lies past MW-165, which contained a detection of RDX at 35 μg/L, and just before MW-210, which did not contain detectable RDX until very recently. Validated groundwater data from samples collected from MW-210 and from MW-211M1, at Pew Road, have not contained detectable RDX. Recent analytical results indicated that unvalidated detections of RDX were measured at MW-210 and MW-211M1. While this extends the length of the RDX plume somewhat, this recent development does not affect the groundwater modeling or remedial system design completed to date.

The maximum width of the RDX plume is approximately 650 ft based on validated groundwater data. Based on the historic use of RDX, its relative mobility once dissolved in water, and its resistance to degradation, it is reasonable that of the explosive compounds, RDX has migrated the furthest from the source. RDX, however, undergoes some limited degradation at Demo 1, as some of the degradation products, hexahydro-1-mononitroso-3,5-dinitro-1,3-triazine (MNX), hexahydro-1,3-dinitroso-5-moninitro-1,3-triazine (DNX), and hexahydro-1,3,5-trinitroso-1,3,5-triazine (TNX) have been observed.

The relatively consistent concentrations of RDX detected in the source-area monitoring well MW-19S (Table 2-2) over four years and 15 rounds of sampling through May 2003 suggest that a continuing source to groundwater contamination existed within the unsaturated materials at Demo 1. However, recent RDX results at monitoring well MW-19S suggest that the source is depleted. The explosive compounds detected in soil and the explosive residuals found within the Demo 1 depression also indicate that source material remains at Demo 1.

Except where RDX is detected at low concentrations (typically less than 2 μg/L), HMX detections in groundwater are co-located with RDX, but at lower concentrations (Figure

2-6 and Table 2-2). The extent of HMX is less than that of RDX, and can be attributed to the lower source strength of HMX. The reduced source strength is consistent with the limited amount of HMX (a 10% impurity in the RDX) used at Demo 1, as confirmed by the lower concentrations of HMX detected in the soil sampling programs compared to RDX.

TNT has migrated the least of the explosive compounds identified for modeling in the FS (Figure 2-20 and 2-21), primarily due to biodegradation, which is the most significant fate-and-transport process for TNT in groundwater. Townsend and Myers (1996) calculated a TNT half-life in groundwater of 28-360 days. Rodacy and Leslie (1992) determined the half-life of TNT to be one year based on work by DuBois and Baytos (1972). Biodegradation occurs under both aerobic and anaerobic environments with the production of the following degradation products: 2A-DNT, 4A-DNT, 2,4-diamino-6-nitrotoluene (2,4-DANT), and 2,6-diamino-4-nitrotolune (2,6-DANT).

Townsend and Myers (1996) indicate that the preferred degradation pathway is TNT→4A-DNT→2,4-DANT. A second pathway is TNT→2A-DNT→2,6-DANT. The findings at Demo 1 are consistent with this study. The presence of 2A-DNT and 4A-DNT in groundwater indicate that the TNT is undergoing the initial biodegradation step (Figure 2-6). The greater downgradient extent of 4A-DNT compared to 2A-DNT also indicates that degradation to 4A-DNT is the dominant pathway at Demo 1, as suggested by Townsend and Myers (1996). The compounds 2,4-DANT and 2,6-DANT have not been detected at Demo 1, suggesting that this step is transitory in nature or that the compounds do not accumulate to detectable levels.

The complete transformation of TNT to its degradation products is further exemplified at Demo 1 by the distribution of explosives in groundwater. The parent compound TNT is present at MW-19S along with daughter products 2A-DNT and 4A-DNT. This association of explosives persists to MW-31 located 600 feet downgradient of MW-19. By the time groundwater reaches the line of wells at MW-74 through MW-78 and MW-114, TNT is no longer detected, whereas 4A-DNT remains. The lack of detection of 2A-DNT and 4A-DNT further downgradient suggests these compounds are also degrading.

The plan-view distribution of RDX in groundwater is presented in Figure 2-7. Figure 2-8 provides interpretive RDX contours for the longitudinal cross section A-A'. As the groundwater flows to the west, the elevation of the top of the RDX plume decreases. This vertical distribution is consistent with historic water level measurements, which indicate a downward vertical gradient at monitoring well, MW-19. Based on numerous water-level measurement events, an average downward vertical gradient of 0.0019 ft/ft has been observed in past measurements between monitoring wells MW-19S and MW-19D. This is likely due to the localized infiltration of precipitation that collects in the bottom of the Demo 1 depression. A distinct vertical gradient is not distinguishable at wells immediately downgradient of monitoring well location MW-19.

Dissolved RDX migrates in the direction of groundwater flow. The plume continues to migrate deeper with increasing distance from MW-19 (Figure 2-8). This increasing plume depth occurs due to the accretion of infiltrating precipitation at the water table. Moreover, infiltrating precipitation west of the depression does not come in contact with residual explosives in the vadose zone. Thus, a lens of clean groundwater exists above the plume, as indicated by data from shallow wells MW-77S, MW-78S, MW-34M3, and MW-165M3.

Low levels of RDX have been detected in the periphery wells MW-74M2 and MW-78M2 at cross section B-B' (Figure 2-9). Figures 2-10 and 2-11 present the distribution of RDX in groundwater at cross sections C-C' and D-D'. The width of the RDX plume that is depicted in Figure 2-8 is strongly influenced by the source width with limited lateral dispersion during migration. The kettle hole is not considered one large homogeneous source area (there are hot spots), however RDX (and perchlorate) are detected across the entire north-south width of the depression. Higher concentrations and more frequent detections of contaminants are typically found in the central 1.25 acres of the Demo 1 depression. This is consistent with the measured concentration distribution within the groundwater plume.

2.7.2 Propellant Compounds

The propellant 2,4-DNT has typically been detected at estimated concentrations at source area monitoring wells MW-19S and MW-31S (Table 2-2). The recent disappearance of 2,4-DNT detections in monitoring well MW-19S and limited extent is expected due to its limited source strength and mobility in the environment.

The perchlorate ion (ClO_4^-) originates as a contaminant in the environment from the solid salts of ammonium, potassium, or sodium perchlorate. It is found in munitions, primarily as a component of explosive initiating devices (fuses) or spotting charges, but also occurs as a constituent of the explosive filler in a limited number of munitions. Ammonium and potassium perchlorate are manufactured for use as the oxidizer component and primary ingredient in solid propellant for rockets, missiles, and fireworks, in addition to being used in some delay compositions, flares, signaling devices, other pyrotechnics, smokes, and tracers.

The propellant perchlorate was first tested for and detected at Demo 1 in August 2000. Since that time, the extent of perchlorate in the Demo 1 plume has been determined to be larger than RDX (Figure 4-3). Because perchlorate has a high solubility, high dissolution rate and low affinity for sorption to aquifer solids, it migrates quickly to the water table. In addition, perchlorate can persist for many decades under typical groundwater conditions due to its resistance to react with other naturally available groundwater constituents.

Figure 2-12 presents the perchlorate concentration contours in groundwater at Demo 1. The highest concentration area for perchlorate is located at MW-76M2 at 500 μg/L (March 2003), which is approximately 1,400 feet from the Demo 1 depression. The highest concentration previously observed for perchlorate was 300 μg/L at MW-114M2 in December 2000. Perchlorate concentrations are dropping at some wells near the source area (MW-19S and MW-31S), which suggests that the source is depleted. (Temporal changes, or pulsing, of perchlorate concentrations relative to plume geometry are described further in Section 3.4.)

As illustrated on the cross-sections (Figures 2-13 through 2-19), the perchlorate plume downgradient of the source area migrates deeper with increasing distance from MW-19. As described above for RDX, this increasing plume depth occurs due to the accretion of infiltrating precipitation at the water table. Thus, a lens of clean groundwater (not containing perchlorate) exists above the plume, as indicated by data from shallow wells MW-75S, MW-77S, MW-78M3, MW-34M3, MW-36S, MW-165M3, MW-172M3, MW-211M3 and MW-231M3.

The longitudinal and lateral extent of the perchlorate plume is larger than the RDX plume at Demo 1 (Figure 2-6). The extent of the perchlorate plume downgradient was determined with monitoring well installations along the power line right-of-way east of Fredrickson Road. Results from the three wells on the power line indicate very low concentrations of 0.49 μg/L at MW-258M3 (35 ft bwt) and 0.56 μg/L at MW-252M3 (10 ft bwt) (see Figure 2-19). These wells are roughly 870 feet apart and well MW-248, located between these wells, did not exhibit perchlorate detections in profile samples or monitoring well samples. This provides clear evidence that the perchlorate plume has been dispersed such that by the power line, concentrations are so low that the plume geometry exhibits a splitting and fingering pattern.

Figures 2-17 and 2-18 illustrate cross-sections E-E' and F-F' (upgradient of the power line), respectively, which depict perchlorate concentrations. Downgradient of Pew Road the perchlorate plume appears to be slightly higher in elevation on the south side of the plume (see Figures 2-18 and 2-19). The width of the perchlorate plume at Pew Road (cross-section F-F') is approximately 1,000 feet. At the power line, although detectable concentrations have been noted in the north and south wells, recently detections are limited to MW-258 to the north. This suggests that the overall width narrows to approximately 200 ft.

3.0 CONCEPTUAL SITE MODEL

The following paragraphs present a Conceptual Site Model that incorporates a description of contaminant sources, contaminant movement, and hydrogeological modeling as presented in the Demo 1 Groundwater Report Addendum to TM 01-2 (AMEC, 2004).

3.1 Source of Contaminants

RDX and the other explosives reside on the soil surface as particulates and residuals (chunks of C4, hand grenades, or flares) deposited as a result of historic demolition training activities. Regrading and filling activities after training events have likely raised the elevation of the ground surface in the Demo 1 depression. Placing fill to create a smoother surface and covering protruding objects for the next event would increase the safety of subsequent military training activities. These regrading and/or filling activities may have resulted in distribution of contaminants to depths of approximately 8 ft below the current ground surface. The contaminants may be in the form of particulates or in a more concentrated source, such as the "burn" pits identified at Demo 1.

Several varieties of pyrotechnics, propellants and munitions formerly used at Camp Edwards contained perchlorate. The explosive and propellant compounds identified as COCs in groundwater at Demo 1 have been repeatedly detected in soil at Demo 1.

3.2 Movement of Contaminants from Soil to Groundwater

The lithologic data for Demo 1 suggest increased clay content near the ground surface, which may contribute to ponding of surface runoff. Ponding increases the contact time between water and explosive residuals resulting in the increased dissolution of contaminants. Drilling logs for the borings in the Demo 1 depression indicate clay and sand are present in the top 7 to 10 ft, and then the soil changes to mostly sand below 10 ft. The reduced infiltration capacity associated with the increased clay content is consistent with the visual observation of ponded water at Demo 1 during the wetter winter and spring months.

Precipitation and snow melt at Demo 1 collect in the bottom of the depression. The EPA Hydrologic Evaluation Landfill Performance (HELP) model was used to assess surface water runoff at Demo 1. Runoff from the Demo 1 slopes adds an additional 50 percent of infiltration to normal infiltration at the bottom of the depression. Conversely, infiltration along the slopes is 20 to 30 percent less than normal infiltration on level ground. The HELP model indicates that runoff from the kettle hole slope occurs primarily in the winter and spring due to snowmelt and deposition of precipitation onto a frozen soil surface. The presence of clay near the ground surface may enhance the retention of RDX in the upper 7 to 10 ft of soil.

Sorption of RDX is primarily dependent upon cation exchange capacity (CEC), pH, clay content, organic carbon, and extractable iron (Ainsworth et al., 1993). The inorganic components of clay soil, iron and cations are more important than organic matter content in predicting sorption (Myers et al. 1998; Haderlein et al. 1996; Leggett 1991; Pennington, 1988; and Leggett, 1985).

The major explosives contaminants, TNT and RDX, have aqueous solubilities of 100 and 42 milligrams per liter (mg/L), respectively, and over time the particulates dissolve into aqueous solution in the environment at Camp Edwards. Perchlorate has an aqueous solubility of 15,000 mg/L as potassium perchlorate, and 200,000 mg/L as ammonium perchlorate (Ashford, 1994). In addition, perchlorate has higher dissolution rates than the explosive compounds. Once in solution, RDX and perchlorate are relatively mobile and will leach through the vadose zone to groundwater. Because of perchlorate's higher solubility and dissolution rates, it will likely leach to the groundwater regime faster than RDX. During rainfall events, overland flow into the depression tends to transport explosives into the depression through the dissolution of contaminants in the sidewall soils and possibly the erosion and transport of explosive and propellant particulates. These processes effectively increase the source strength and focus recharge to groundwater over a smaller area. Water passing through soil at the base of the depression further dissolves the contaminants, a process that is dependent on the dissolution rates of the compounds. The dissolution rates of the explosives are, in decreasing order, HMX, RDX, TNT, and DNT. In most cases, explosives residuals are likely to be present in surface soil even after groundwater impacts have occurred because the solid residue on the ground surface would not be completely dissolved. This is consistent with the observation of explosive residues present in surface soils.

It is possible for groundwater contamination to exist in the absence of a currently measurable source in soil in instances where the explosives or propellants were deposited as small particles and/or the releases occurred long enough in the past for the particulates to have dissolved. The dissolution rate is largely a function of the surface area of the particulates; the smaller the particles, the greater the surface area and the faster they would dissolve. Several other factors affect the rate of dissolution, such as the length of time water is in contact with the particles, the degree of weathering of the particulates, evapotranspiration rate, and temperature. The residual explosives (C4) found at Demo 1, along with the detections of explosives and propellants in soil suggest that a continuing source of contamination was present at the ground surface. However, based on groundwater results at the source area (MW-19S), the source has been depleted due to prior and ongoing soil remediation efforts.

Once in solution, RDX and perchlorate readily move through the unsaturated soil column to the water table leaving relatively little residual contamination below the zone of particulate deposition and reworked soil. In contrast, TNT is degraded and adsorbed onto the soil leaving detectable residuals in soil, with only a small portion reaching to greater depths in the subsurface environment. DNT behavior is expected to be similar to TNT. HMX mobility falls somewhere between these two extremes.

In deeper soils at Demo 1, RDX and other explosives were not consistently detected in individual soil borings. (Subsurface soil samples from Demo 1 have not been analyzed for perchlorate). The absence of consistent contaminant detections with depth is related to the mechanism by which RDX and other explosives are released to the environment. Water from individual precipitation events will move through the unsaturated zone as a wetting front. The extent (thickness) of the wetting front is dependent upon the intensity and duration of the precipitation event as well as the hydraulic properties of the soil, which control how fast water moves. Beyond 10 ft in depth, the subsurface at the Demo 1 depression comprises high permeability sands. Detectable levels of RDX are likely only present in the wetting fronts. The intervening soil layers may have some RDX sorbed to the soil surface or dissolved into interstitial water or dead end pores. However, the mass of RDX present is likely to be very small relative to the total mass of soil analyzed. Therefore, RDX would not be expected above current analytical detection limits for soil in the unsaturated zone at Demo 1 in the absence of a wetting front. It is also possible that the sporadic RDX detections with depth could reflect preferential flow within the unsaturated zone.

3.3 Movement of Contaminants in Groundwater

As discussed above, RDX and perchlorate will readily leach to the groundwater, with perchlorate more readily dissolving than RDX. In addition, there is evidence that RDX is slightly retarded in the environment due to limited sorption. Therefore, RDX will generally move at a velocity slightly less than that of normal advective flow, while perchlorate will move generally at the same rate as the advective front. Longitudinal dispersion is a significant transport process for both perchlorate and RDX.

The longitudinal and lateral extent of the perchlorate plume is larger than the RDX plume at Demo 1. The combination of higher solubility, higher dissolution rates, and lower sorption rates has allowed perchlorate to travel further in the groundwater regime and impact a larger portion of the aquifer. Based on results through May 2003, the downgradient extent of the RDX plume is interpreted to reach MW-210, approximately 4,600 feet downgradient of the source, whereas the perchlorate plume is 9,200 feet long. However RDX was recently detected at low concentrations (less than 1 μg/L) in monitoring wells MW-210M2 and MW-211M1. The widest downgradient width of the RDX plume is approximately 650 ft, whereas the widest extent of the perchlorate plume is approximately 1,400 ft, roughly two times the observed width of the RDX plume.

Vertical dispersion does not appear to significantly affect the RDX plume migration at Demo 1. The results of the fate and transport modeling for the RDX plume indicate that the advective flow path under average water conditions did adequately describe plume geometry with depth.

The subsurface geology and groundwater gradients also control the migration of contaminants in groundwater. In the BBM area (downgradient of Frank Perkins Road), the overall transmissivity of the saturated zone decreases, horizontal gradients steepen, and vertical gradients change. Aside from the minimal localized downward gradient directly below the Demo 1 depression, groundwater elevation data indicate there is largely horizontal flow all the way to Pew Road. As discussed in Section 2.3, preliminary groundwater elevation data indicates that slight downward gradients occur along Pew Road, significant upward gradients appear near the toe of the plume area (MW-225 and MW-231), and slight downward gradients again appear at the edge of the plume along the power line (MW-248, MW-252, MW-258).

Evaluation of Figures 2-13, 2-17, 2-18 and 2-19 indicates that the perchlorate plume thins to approximately 50-feet thick at Pew Road. In this area the plume is located above a clay and silt zone, which appears to be continuous in the direction perpendicular to flow as shown on Figure 2-17. The plume maintains this higher elevation and thickness to monitoring wells MW-231 and MW-225 located 400 feet downgradient. The lower permeability clays and silts slow contaminant migration to greater depths (Figure 2-13). This observation coupled with steeper horizontal gradients in this area and slight downward gradients along Pew Road and significant upward gradients at the toe of the plume give further evidence that the toe of the plume area west of Pew Road has an increasingly complex hydrogeologic regime. Monitoring of this area will continue.

3.4 Pulsing of Contaminants in Groundwater

It is likely that differing concentrations of contaminants were introduced to the ground surface at Demo 1 at different times as a result of periods of higher or more concentrated use for demolition training or disposal activities. This results in temporal variations in concentration loading to the ground surface and hence to the groundwater regime over time. Therefore, pulses of higher and lower concentrations are likely to move through the subsurface. Ongoing groundwater monitoring will help to evaluate contaminant pulsing, if discernable, within the plume. Precipitation and run-off events do not take place on a consistent basis and are of varying magnitude. More contaminants are likely to be dissolved and transported to the water table during significant precipitation and ponding events, thereby producing pulses of varying degrees of groundwater contamination.

RDX detections in MW-31 may portray the effect of pulsing within the plume. Monitoring well MW-31S has been sampled on seven separate occasions for explosives (Table 2-2). In chronological order, samples from MW-31S have contained RDX at 64, 210, 50, 110, 140, 120, 81, 88, 31, 130, 85, 11, 86, 63, and 21 μg/L. Preliminary analysis does not indicate that the variations in concentration result from seasonal variations in groundwater elevation. Further, the variation in concentration does not appear to reflect the precision and accuracy of the analytical method.

3.5 Estimate of the Contaminant Volume and Mass

The analytical data collected for the Demo 1 plume were plotted spatially onto Figures 2-6 through 2-21. The plume shells were interpolated and rendered in three dimensions in the groundwater modeling process. The estimated volume and mass of the contaminant plumes for perchlorate, RDX and TNT are presented below.

COC	Estimated Volume		Estimated Mass	
	Liters	Gallons	Kilograms	Pounds
Perchlorate	5.5E09	1.46E09	45	100
RDX	1.2E09	3.15E08	30	67
TNT	4.7E07	1.2E07	0.06	0.13

3.6 Groundwater Modeling

IAGWSP established the modeling program to focus on the northern portion of the MMR, where it has conducted environmental investigations since 1997. The methodology has been to continually update the regional flow model by incorporating site-specific lithologic and hydrogeologic information from field investigations, related studies and literature as it becomes available. This process is iterative because simulated flow paths from the updated regional model are used to help guide characterization activities.

Subregional flow and transport models are developed from the updated regional model using telescopic mesh refinement (TMR) techniques. The USGS MODTMR code (Leake and Claar, 1999) is used to facilitate construction of the subregional models. MODTMR constructs embedded subregional models by extracting boundary conditions and hydraulic parameter distributions from the regional model and projecting those values onto the local grid of the subregional model. Detailed hydrologic information is then input into the subregional models, which are used to more precisely simulate groundwater flow and contaminant migration and to design and evaluate remedial scenarios. Ultimately, post-installation performance data from the selected remedial system design will be used to iteratively improve the subregional model and optimize remedial operations.

In late 2002, a comprehensive update of the MMR regional model was initiated to incorporate new information and improve the model's predictive capabilities. The new model is referred to as MMR-10. The primary objectives of this update were to:

1) Refine the model grid spacing from 660 x 660 ft to 330 x 330 ft;
2) Calibrate to groundwater elevations measured in 2000 and a revised interpretation of the location of the top-of-mound (TOM) based on 2000 data;
3) Incorporate new data on bedrock elevations;
4) Update hydraulic conductivity distributions based on pumping tests performed in the Impact Area and elsewhere in the northern portion of MMR;
5) Improve the match between predicted and observed Demo 1 plume trajectory;
6) Calibrate to a number of other data sets including tritium-helium isotope groundwater ages and stream flow measurements provided by the USGS; and
7) Incorporate some recent findings and regional model revisions by the USGS and Jacobs Engineering into the new regional model.

MMR-10 was then used to develop the Demo 1 subregional model of groundwater flow and contaminant transport to support the Demo 1 Feasibility Study. A draft Feasibility Study conducted previously for Demo 1 (AMEC, 2001d) considered the RDX plume only in quantifying the ability of each alternative to capture and remove mass, and to reduce concentrations. Since that time perchlorate has been identified as an additional COC and plume delineations have changed considerably as summarized in the Final Groundwater Addendum (AMEC, 2004b). Development and calibration of MMR-10 was completed in June 2003.

Appendix A contains a detailed description of the regional and sub-regional flow models as well as the transport runs conducted as part of this FS. Also described in detail is the Particle Tracking Optimization (PTO) algorithm used to generate conceptual designs presented in the engineering analysis. This algorithm was instrumental in facilitating the evaluation of thousands of potential extraction well placements before finding the optimal combination of well number, well location, pump rate, and pumping duration to achieve a specified mass removal goal. Once optimized using the contaminant mass removal goal, the well locations and pump rates were input into a transport model for each COC to estimate the contaminant concentration distribution over time.

4.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

This section identifies remedial response and remedial action objectives that form the basis for identifying remedial technologies and developing remedial alternatives. General response actions to satisfy those objectives are also identified. Candidate technology process options are screened based on their applicability to site and waste characteristics.

This section of the FS is mostly excerpted directly from the Draft FS, Demo 1 Groundwater OU (AMEC, 2001d).

4.1 Remedial Response Objectives

Remedial response objectives are site-specific, qualitative cleanup objectives established on the basis of the nature and extent of contamination, the resources currently or potentially threatened, and the potential for human and environmental exposure. AO3 (Appendix B, Section 3.0, I) identified the following remedial response objectives for Camp Edwards:

1. *Provide a level of protection to the aquifer underlying the Training Ranges and Impact Area that accounts for the following information provided by USEPA:*

   a. That the Cape Cod aquifer is a single continuous aquifer which then served as the "sole source" of drinking water for the approximately 147,725 permanent residents and 424,445 peak seasonal residents of Cape Cod;

   b. There is no existing alternative drinking water source, or combination of sources, which provides fifty percent or more of the drinking water to the designated areas, nor is there any reasonably available alternative future source capable of supplying Cape Cod's drinking water demands;

   c. As a result of its highly permeable soil characteristics, the Cape Cod aquifer is susceptible to contamination through its recharge zone from a number of sources. Since groundwater contamination can be difficult or impossible to reverse, and since this aquifer is relied on for drinking water purposes by the general population, contamination of the aquifer would pose a significant hazard to public health;

   d. The Training Range and Impact Area lie directly over the Sagamore Lens, the most productive part of the Cape Cod Aquifer. The Training Range and Impact Area is a major groundwater recharge Area, located above what may be the apex of the Sagamore Lens. Groundwater flows radially in all directions from the Training Range and Impact Area;

   e. The part of an aquifer that directly supplies a public water supply well is known as a "wellhead protection Area". The Training Range and

Impact Area lie directly above segments of several wellhead protection areas on Cape Cod; and

f. The Sagamore Lens has been identified by the Cape Cod Commission as the portion of the Cape Cod Aquifer most capable of supplying sufficient water to satisfy future demand.

2. *Protect human health and the environment by recycling waste or by, eliminating, reducing, and/or controlling risks to human health and the environment posed through each pathway at the Area of Concern;*

3. *Consider the long-term uncertainties associated with land disposal;*

4. *Consider the goals, objectives, and requirements of the Solid Waste Disposal Act;*

5. *Consider the persistence, toxicity, mobility, and the propensity to bioaccumulate contaminants;*

6. *Consider the short and long term potential for human exposure;*

7. *Consider the potential threat to human health and the environment if the remedial alternative proposed was to fail; and*

8. *Consider the threat to human health and the environment associated with the excavation, transportation, and redisposal or containment of contaminated substances and/or media.*

4.2 Remedial Action Objectives

Remedial action objectives specify the COCs, media of interest, exposure pathways, and Preliminary Remediation Goals (PRGs) to be used in developing remediation technologies.

The overall remedial action objective for groundwater at Demo 1 is to protect and restore a localized contaminated area within the sole source aquifer. The specific remedial action objective as defined in AO3 is to:

> *Prevent potential ingestion and inhalation of water containing COCs (RDX, HMX, 2,4-DNT, 2A-DNT, 4A-DNT, TNT and perchlorate) in excess of background levels (to the extent technically feasible), federal maximum contaminant levels (MCLs), Health Advisories, Drinking Water Equivalent Levels (DWELs), or an unacceptable excess lifetime cancer risk or non-cancer Hazard Index*.

Table 4-1 presents the proposed background and risk-based or regulatory concentration goals for RDX, TNT and perchlorate as required in AO3. Through agreement with the EPA and DEP (AMEC, 2003e), background concentration values for use in the FS modeling are equal to the analytical reporting limit of 0.25 µg/L for both RDX and TNT and the method detection limit of 0.35 µg/L for perchlorate (Table 4-1). The agreed upon values to be used for the regulatory standards or risk-based concentrations are as follows: 0.6 µg/L for RDX, 1.0 µg/L for perchlorate, and 2.0 µg/L for TNT (Table 4-1).

4.3 General Response Actions

General response actions describe categories of remedial actions that may be employed to accomplish remedial action objectives. General response actions may include treatment, containment, excavation, extraction, disposal, institutional actions, or a combination of these actions. Like remedial action objectives, general response actions are medium specific. At the 09/11/03 Revised Draft FS Scoping Meeting, EPA and DEP agreed that the IAGWSP would present collection (extraction), treatment, and discharge (recharge) actions. Specifically, the IAGWSP proposed that the Revised Draft FS would focus on optimization of extraction, treatment and recharge scenarios for Demo 1 groundwater. These actions would be combined with institutional controls and long-term monitoring to protect human health and the environment for the comprehensive remedy. The Draft FS (AMEC, 2001d) presents a thorough list of general response actions, potential remedial technologies and process options which is incorporated herein by reference.

4.4 Identification of Technologies and Process Options

The Final Evaluation of Remediation Technologies for Demolition Area 1 (Ogden, 2000c) evaluated remedial technologies to address explosive contaminants present in soil and groundwater. Categories of remedial technologies and specific process options were identified based on a review of the literature, vendor information, performance data, and experience in developing other feasibility studies and were presented in the Draft FS (AMEC, 2001d).

4.5 Screening of Technology Process Options

The technology screening process assesses each technology process option for its probable effectiveness, implementability, and relative cost with regard to site-specific conditions, known and suspected contaminants, and affected environmental media. The effectiveness evaluation focuses on: (1) whether the technology is capable of handling the estimated areas or volumes of environmental media and meeting the contaminant reduction goals identified in the remedial action objectives; (2) the effectiveness of the technology in protecting human health during the construction and implementation phase; and (3) how proven and reliable the technology is with respect to the contaminants and conditions at the site. Implementability encompasses both the technical and institutional feasibility of implementing a technology. Relative cost is evaluated as a final means of comparison between process options. A detailed screening of a comprehensive list of technology process options was presented in the Draft FS (AMEC, 2001d).

Based on the Draft FS, subsequent ITE studies, and industry literature, fluidized bed reactor (FBR), GAC media and IX resins were retained as potential treatment process options. During development of the FS, the EPA requested that only one treatment train be carried through the detailed evaluation (AMEC, 2001d). That approach limits the length and complexity of the study, and keeps the study focused on the effect of remediation on the aquifer itself, rather than on the ex situ treatment methodology of the alternatives. Table 4-2 presents the basis for selection of the technology process options.

4.5.1 Fluidized Bed Bioreactor

A FBR treats contaminants in water by biodegradation. A FBR system consists of a reactor vessel containing a granular medium that is colonized with active bacterial biofilm. The upward flow of groundwater through the vessel fluidizes the bed. As summarized in Appendix B, bench scale studies conducted with water collected from MMR have demonstrated the FBR technology to be effective in treating perchlorate and partially effective at treating explosives. In addition, full-scale FBR systems are currently operating at other sites to treat perchlorate.

Although FBR treatment has been shown to be effective, it does not represent a cost effective technology when compared to IX resin or even GAC media for treatment of very low concentrations of perchlorate. Currently, FBR treatment has not been used in a full-scale basis to treat perchlorate concentrations in groundwater at such low concentrations anticipated at Demo 1. The increased costs associated with building a taller structure to house the FBR, the chemical feed systems and their associated chemical storage rooms, and the additional fire protection requirements, significantly increase the overall capital costs for the FBR technology. Therefore, FBR was not chosen as part of the treatment train in the detailed analysis.

4.5.2 Granular Activated Carbon Media

GAC adsorption is a separation technique. When water passes through the porous GAC, contaminants are attracted to and held on the surface of the GAC. Compounds are removed from water, but are not destroyed. Once the capacity of the GAC has been exhausted, breakthrough occurs (i.e., contaminants in effluent) and the GAC needs to be either regenerated or replaced. GAC media is widely used for the removal of many contaminants.

To assess the efficacy of GAC to treat very low concentrations of perchlorate, the IAGWSP, has conducted several ITE studies (AMEC, 2001c; AMEC 2002c; AMEC 2003c; AMEC, 2004b). The results of these studies indicated that GAC would effectively treat low levels of perchlorate, similar to those expected from the extraction wells at Demo 1. EPA and DEP approved the use of GAC media to treat low levels of perchlorate (less than 3 µg/L) expected at the Pew Road treatment system under the RRA Plan. However, EPA did not approve of GAC treatment for the RRA treatment system at Frank Perkins Road partially due to slightly higher expected influent concentrations (5-20 µg/L). EPA indicated that treatment of perchlorate using GAC media is not a proven technology and has not been demonstrated to be effective at full-scale operation. Appendix B contains additional details.

GAC is a viable treatment option for explosives. Standard GAC can be effectively used to remove explosives such as RDX and HMX. It is a common technology and is currently used at other sites. Several reports have studied the adsorption of explosive compounds found in groundwater on GAC at munition facilities (Hinshaw et al. 1987; Wujcik, Lowe and Marks 1989; Dennis et al. 1990; and Calgon Carbon 1988). Sites that have used standard GAC for treatment of explosives include Pantax Plan, Amarillo, TX

(Henke, et al, 1998), the Radford Army Ammunition Plant (AAP), Louisiana AAP; Iowa AAP; and Kansas AAP (Hinshaw et al, 1987).

4.5.3 Ion Exchange Resin

Ion exchange is a physical-chemical process by which ions like perchlorate are transferred from the liquid phase to the solid phase. Ions held by electrostatic forces to charged functional groups on the surface of the solid are exchanged for ions of similar charge in a solution in contact with the solid. Similar to GAC treatment, treatment with IX resin occurs via flow through a porous media.

IX resin removes ions such as perchlorate from the water and exchanges them for chloride ions bound to the resin. Although certain ion exchange resins have been shown to sorb perchlorate, the same resins do not sorb the target explosives compounds due to the different chemical nature of the compounds. Perchlorate is an anion, which is attracted to the positively charged surface of IX resins, replacing chloride ions. Explosives such as RDX and HMX do not have an ionic charge and are not attracted to the resins. Therefore, other means of treatment would be required to treat the explosives in the water exiting the IX vessels.

Information is not readily available on whether IX resins can remove perchlorate to the 0.35 µg/L method detection limit, which was the background concentration set by EPA (AMEC, 2003e). An informal survey of sites using IX resins for remediation indicated that the site managers were reluctant to discuss whether IX resins are effective in removing perchlorate to concentrations of 0.35 µg/L. ITE studies are currently being conducted to provide this information.

EPA and DEP have approved the use of IX resin for treatment of perchlorate contaminated groundwater as part of the treatment system for Frank Perkins Road under the RRA Plan.

Until recently, the cost of various non-regenerable IX resins was considered prohibitive for treatment of low concentrations of perchlorate. However, costs have decreased in the last year due to competitive market factors. These resins would likely be appropriate for treatment of low concentrations of perchlorate such as at the Frank Perkins Road ETR System. These costs saving are a factor in making IX a more feasible option than FBR in treating perchlorate.

As previously summarized, little information is available on IX treatment of low levels of perchlorate (i.e., less than 15 µg/L). Available design information has been limited to vendor information provided to AMEC from Purolite (Purolite, 2004). Based on this vendor information, the conceptual IX design will be based on a minimum bed depth of 3 feet and a cross sectional flow rate of 6 gpm/ft^2.

4.5.4 Selected Technology Process Options

As summarized in Section 6, each of the comprehensive alternatives except the minimal action alternative for Demo 1 would consist of two treatment systems. One treatment system will treat groundwater extracted from the upgradient portion of the plume (Frank Perkins Road system) and the other system will treat water extracted from the downgradient portion of the plume (Pew Road system). The Frank Perkins Road system is expected to treat low concentrations of perchlorate and explosives and the Pew Road system is expected to treat only very low levels of perchlorate. Section 6 contains additional detail on the flow rates and anticipated influent concentrations.

For the Frank Perkins Road system, the selected treatment train that will be retained for detailed analysis will consist of perchlorate treatment utilizing an IX system and explosive treatment utilizing a GAC system. Note that the term “system” as used herein may refer to one or more vessels in series or parallel. The primary reason for this selection was the lack of confidence expressed by EPA and DEP in the ability of GAC to effectively treat the slightly higher concentrations of perchlorate expected at FPR. The treatment media selection will be re-evaluated based upon results of ITE studies, site-specific performance and industry literature.

For the Pew Road system, a mobile treatment container system will be utilized. The mobile treatment container system will utilize GAC for treatment of low levels of perchlorate

5.0 DEVELOPMENT OF ALTERNATIVES

This section identifies the range of remedial alternatives under consideration, and describes the development of comprehensive remedial alternatives for contaminated groundwater at Demo 1. Some of this information was initially presented in the Final Technical Team Memorandum, Development and Initial Screening of Alternative Report, Demo 1 Groundwater OU (AMEC, 2001e) and in the Draft FS (AMEC, 2001d).

Based on discussions among the IAGWSP, DEP and EPA at the FS planning meeting on 09/11/03, it was agreed that the alternatives under consideration in this Revised Draft Feasibility Study would include and consider various ETR systems to meet the requirements of AO3. This was proposed for two reasons: 1) The draft FS considered in-situ treatment technologies which were ultimately not practical given the site conditions, and 2) The groundwater RRA being implemented at Demo 1 consists of groundwater extraction, ex-situ treatment and recharge via injection wells and the components of the RRA ETR Systems will be incorporated, to the extent feasible, into the FS remedial alternatives.

5.1 Range of Alternatives

Treatment alternatives under consideration represent configurations of extraction well field designs to meet the remedial action goals within the aquifer in the allotted timeframes. The alternatives developed for groundwater include the following, per AO3 (Appendix B, Section 3.0, II, B, 2).

a. *An alternative that, throughout the entire soil, source, and/or groundwater plume, reduces the contaminant concentrations to background conditions to the extent technically feasible.*

b. An alternative that, throughout the entire soil, source, and/or groundwater plume, reduces the contaminant concentrations to levels that meet or exceed all MCLs, Health Advisories, DWELS, other relevant standards, and a cumulative 10^{-6} excess cancer risk. It shall achieve this objective as rapidly as possible and must be completed in less than ten (10) years and shall require no long-term maintenance, to the extent feasible.

c. A no action alternative to serve as a baseline for alternative comparisons.

d. For source-control actions, a range of alternatives in which treatment that reduces the toxicity, mobility, or volume of the contaminants is a principal element. As appropriate, this range will include an alternative that removes or destroys contaminants to the maximum extent feasible, eliminating or minimizing, to the degree possible, the need for long-term management. This range will include other alternatives which, at a minimum, will treat the principal threats posed by the AOC but vary in the degree of treatment employed and the quantities and characteristics of the treatment residuals and untreated waste that must be managed.

e. *For groundwater response actions, a limited number of remedial alternatives will be developed that attain site-specific PRGs within different restoration time periods utilizing one or more different technologies if they offer the potential for comparable or superior performance or implementability; fewer or lesser adverse impacts than others available approached; or lower costs for similar levels of performance than demonstrated treatment technologies*.

As discussed in Section 4.2, background concentrations for use in the FS modeling are equal to the analytical reporting limit of 0.25 µg/L for both RDX and TNT and the method detection limit of 0.35 µg/L for perchlorate (Table 4-1). The agreed upon concentrations to be used for the regulatory standards or risk-based values are as follows: 0.6 µg/L for RDX, 1.0 µg/L for perchlorate, and 2.0 µg/L for TNT (Table 4-1).

5.2 Development of Alternatives

Five remedial alternatives were developed to address the remedial action and response objectives presented in Section 4.0. A sixth alternative was added at the request of EPA and the DEP. These alternatives include:

Alternative 1: Minimal Action
Alternative 2: Baseline
Alternative 3: Background
Alternative 4: 10 Year
Alternative 5: Additional Alternative A
Alternative 6: Additional Alternative B

Appendix A and Section 6.0 provide additional detail on the development and configuration of these alternatives. Based on the focused approach agreed to for this Revised Draft FS, screening of the alternatives was not conducted and the six alternatives are retained for detailed analysis (Section 6.0).

Table 5-1 indicates how the range of six alternatives chosen for detailed evaluation satisfies the requirements of AO3.

6.0 DETAILED ANALYSIS OF ALTERNATIVES

6.1 Introduction

The following subsections describe the criteria for the detailed analysis, the development of a conceptual design for each alternative and the evaluation of each alternative against these criteria.

6.1.1 Development of Conceptual Design for Each Alternative

The conceptual design for each of the six alternatives, except the minimal action alternative, included the following components:

- Layout of extraction wells and estimated groundwater extraction flow rates;
- Type and size of primary treatment units;
- Layout of injection wells and associated injection flow rates;
- Mass balance to assess remediation efficiency and estimate residuals from treatment;
- Preliminary schedule for construction and operation; and
- Preliminary cost estimate.

The type and size of primary treatment units were based on certain assumptions and the current understanding of the treatment technologies. The actual treatment may change during the detailed design phase and as updated information is attained from treatment studies and the general industry. For Alternatives 3 through 6, and as noted in Appendix C, the design assumptions included the following:

- Frank Perkins Road GAC design is based on 10 minute EBCT.
- Frank Perkins Road ion exchange design is based on 3 ft bed depth and 6 gpm/ft^2.
- Pew Road GAC design is based on 5 minute EBCT.
- The treatment System at Pew Road would continue to utilize mobile container(s). For cost estimating purposes, each mobile container system is assumed to require replacement every 10 years with a new container system.

Each conceptual design incorporated numerous assumptions, as described in the text below. Such assumptions are particularly critical when considering two aspects of a conceptual design: the estimated rate of mass removal (i.e., remediation efficiency), and the estimated costs of remedial actions. The basis for each of these estimates is described briefly below to provide the reader with the context for the detailed evaluation.

<u>Estimates of Mass Removal and Time to Achieve Cleanup Goals</u>

Groundwater analytical data collected from monitoring wells within the Demo 1 groundwater plume were used to interpret a plume boundary and interpolate concentration distribution within the plume. Two-dimensional interpretations of the plume in plan view, in longitudinal cross-section, and in orthogonal cross-section were constructed. These interpolations were then synthesized to form a three-dimensional plume shell image. This interpretation was used to derive 10 to 20 ft thick model layers for input to the groundwater model. An analytical solution was used to calculate the plume volume and total estimated mass for RDX and perchlorate within the interpolated groundwater plume extent. Similarly, the effectiveness of each Alternative over time was measured by comparing the estimated mass remaining after system operation to the original mass estimate. The percentage of mass removed from the groundwater plume for each Alternative was plotted against time.

Development of Cost Estimates

The next step is to prepare an order of magnitude cost estimate for each alternative. These estimates are intended to be accurate to within +50/-30% of the final cost. Each estimate includes the following components (U.S. ACE and U.S. EPA, 2002):

- Capital costs, which are those expenditures required to initiate and install a remedial action.
- Operation and Maintenance costs, which are post-construction costs necessary to ensure the continued effectiveness of the remedial action. O & M costs may include, for example, operators' labor, chemicals, power, monitoring, equipment replacement, disposal of treatment residuals, and reporting.
- Present worth analyses, which are described further below.
- Indirect costs, including contingencies and engineering services; and
- Sensitivity analyses.

The present-worth cost (or present value) of operation and maintenance represents the amount of money which, if invested in the initial year of the remedial action and paid out for operation and maintenance as needed, would suffice to cover all of the operation and maintenance costs during the project's life. To calculate the present-worth cost, one must assume an interest rate and an inflation rate. Alternatively, one can assume a discount rate, which represents the rate of return on investments after inflation (therefore, inflation need not be factored into the calculation separately). Real discount rates from Appendix C of the federal Office of Management and Budget (OMB) Circular A-94 should generally be used for all Federal facility sites. The present worth cost estimates presented in this report incorporate a discount rate range of 2.8 to 3.5% (Appendix C). Present-worth calculations are also based on the project duration. The project duration generally begins with the planning, design, and construction of the remedial alternative, continues through short- and long-term O&M, and ends with project completion and closeout. Each remedial alternative typically has different project durations.

6.1.2 Criteria for Detailed Evaluation

The detailed analysis of alternatives consists of an assessment of individual alternatives against each of nine evaluation criteria and a comparative analysis that focuses upon the relative performance of each alternative against those criteria. The nine criteria are:

1. Overall protection of human health and the environment, focusing on whether the alternative achieves adequate protection. Documentation should describe how site risks posed through each exposure pathway being addressed are eliminated,

controlled, or reduced. This evaluation also allows for consideration of whether an alternative poses any unacceptable short-term or cross-media impacts. This criterion draws on the assessments conducted under other criteria.

2. Compliance with regulations, including:

    - Federal regulations.
    - State regulations.
    - Local regulations.

3. Long-term effectiveness and permanence, considering

    - The magnitude of risks remaining after completion of the remedial action; and
    - The adequacy and suitability of controls, if any, that are used to manage treatment residuals or untreated wastes remaining at the site.

4. Reduction of toxicity, mobility, and volume through treatment, including

    - The treatment processes the remedy will employ and the materials they will treat;
    - The amount of hazardous materials that will be destroyed or treated, including how the principal threat(s) will be addressed;
    - The degree of expected reduction in toxicity, mobility or volume measured as a percentage of reduction (or order of magnitude);
    - The degree to which treatment will be irreversible;
    - The type and quantity of treatment residuals that will remain following treatment; and
    - Whether the alternative would satisfy the preference for treatment as the principle element.

5. Short-term effectiveness, including

    - Protection of the community during the remedial action (e.g., from impacts from dust, transportation);
    - Protection of workers during remedial action;
    - Environmental impacts; and
    - Time until remedial response objectives are achieved.

6. Implementability, considering

    - Technical feasibility, including
        - Construction and operation;
        - Reliability of technology;
        - Ease of undertaking additional remediation, if future remedial actions must be taken or other operable units addressed;
        - Monitoring considerations, addressing the ability to adequately monitor the effectiveness of the remedy and the risks should monitoring be insufficient to detect a system failure.

- Administrative feasibility, including activities to coordinate with other regulatory agencies;
- Availability of services and materials, including
- Availability of adequate offsite treatment, storage capacity, and disposal services;
- Availability of necessary equipment and specialists, and any other necessary resources;
- Availability of services and materials, plus the potential for obtaining competitive bids (especially for innovative technologies); and
- Availability of prospective technologies.

7. Cost, considering

- Capital costs, both direct and indirect;
- Annual operation and maintenance costs;
- Accuracy of cost estimates;
- Present worth analysis (or net present value) of costs; and
- Sensitivity analysis, considering uncertainties in factors such as
    - The effective life of the remedial action;
    - The O&M costs;
    - The duration of clean up;
    - The volume of contaminated material;
    - Other design parameters;
    - The discount rate.

8. State Acceptance, considering the technical and administrative issues and concerns that the state may have regarding the alternative. This criterion will be continuously evaluated throughout the development and screening of alternatives process based on comments and input received from DEP and finalized based upon comments received on the FS Report and the Remedy Selection Plan.

9. Community Acceptance, which entails an evaluation of issues and concerns the public may have regarding each alternative. This criterion will be continuously evaluated throughout the development and screening of alternatives process and finalized based on comments received on the FS and the Remedy Selection Plan.

6.2 Alternative 1 – Minimal Action

Alternative 1 provides a minimal action alternative for evaluating other remedial alternatives. The minimal action alternative would follow a shut-down of the groundwater ETR systems currently under construction for the groundwater RRA. Alternative 1 includes long-term groundwater monitoring and institutional controls.

The major components of this alternative include:

- Long-term groundwater monitoring; and
- Institutional controls.

6.2.1 Description

A minimal action alternative provides a cost baseline to compare with other alternatives per AO3 (Appendix B, Section 3.0, II, B, 2c).

6.2.1.1 Assumptions

The costs of this alternative are based on the following assumptions:

- 6 additional monitoring wells will be installed for long-term monitoring of the groundwater plume;
- Costs for periodic monitoring at 12 wells are included in this cost estimate to account for existing wells on-site; and
- Costs are estimated for a 50 year time period.

6.2.2 Conceptual Design

6.2.2.1 Long-term Monitoring

Long-term groundwater monitoring associated with the Demo 1 plume would continue using the same sampling and analytical protocols currently in use. Baseline monitoring of the site conditions and potential environmental impacts will be monitored according to the System Performance and Environmental Impact Monitoring (SPEIM) Plan. The SPEIM, which will be submitted to the EPA and DEP in June 2004, will outline all sampling associated with long-term groundwater monitoring.

6.2.2.2 Institutional Controls

As long as the plume area is within the sole purview and control of the Army, groundwater use restrictions are not needed. However, should the Army transfer its lease to another entity, institutional controls would be established upon lease transfer. The current lease agreement is in effect until 2052. Institutional controls could include deed restrictions that would prohibit the placement of drinking water supply wells where their zone of contribution would intercept the Demo 1 groundwater plume.

6.2.2.3 Site Closeout

Following completion of the proposed activities several measures would be taken to properly abandon and remove the system associated with this alternative. Site closeout for this alternative would include the following two actions:

- All monitoring wells would be properly abandoned at the site.

6.2.2.4 Schedule

The RRA System would run until the comprehensive remedial action alternative was selected and implemented. This alternative would be in effect starting in 2008.

6.2.3 Detailed Evaluation

6.2.3.1 Overall Protection of Human Health and the Environment

Alternative 1 will not prevent the migration of the plume off Camp Edwards. Short-term impacts would be limited. Vegetation will not be impacted because Alternative 1 simply entails long-term monitoring of groundwater, which is currently ongoing.

6.2.3.2 Compliance with Regulations

Alternative 1 could comply with applicable regulations but would not meet the objectives of AO3. Supporting information is provided in Appendix D.

6.2.3.3 Long-Term Effectiveness and Permanence

No action would be taken to reduce the residual risk at this site. No one is currently drinking contaminated groundwater as a result of the Demo 1 groundwater plume. Long-term migration of the plume is not expected to flow into a zone of contribution for the Bourne public water supply wells. Residual site risk is expected to be moderate.

6.2.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

No treatment would occur, therefore no reduction in toxicity, mobility, or volume would occur through treatment.

6.2.3.5 Short-Term Effectiveness

There would be little effect on the community from implementing Alternative 1 because no construction work would be involved. A site-specific health and safety plan (HASP) would be followed during long-term groundwater monitoring and personal protective equipment (PPE) would be used as necessary to prevent potential exposure to COCs. No impact would occur to the environment as a result of this Alternative since no action would be taken. The Minimal Action Alternative would not meet the Remedial Response or Action Objectives.

6.2.3.6 Implementability

Implementability involves technical feasibility, administrative feasibility, and availability of services and materials. Alternative 1 is a minimal action alternative that requires no technical implementation.

Long-term groundwater monitoring associated with the Demo 1 plume would continue using the same sampling and analytical protocols currently in use. Baseline monitoring of the site conditions and potential environmental impacts would be monitored according to the SPEIM Plan, which will be submitted in June 2004 and will outline all sampling associated with system operation and maintenance. Administratively, this alternative is feasible.

If the existing lease is terminated, expires, or is transferred, deed restrictions prohibiting the installation of water supply wells within the area of impacted groundwater would be negotiated with the Commonwealth of Massachusetts. In the interim, the Army would restrict any development of drinking water supplies in areas that would be impacted by the existing groundwater plume.

6.2.3.7 Costs

The costs were estimated for Alternative 1 as follows:

- Capital cost: $ 1,550,000;
- Present worth of O & M: $ 1,300,000; and
- Total present worth: $ 2,850,000.

Appendix C provides detailed calculations of the cost of Alternative 1.

6.2.3.8 State Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process based on comments and input received from DEP, and finalized based upon comments received on this Revised Draft FS and the Draft Remedy Selection Plan.

6.2.3.9 Community Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process and finalized based on comments received on the Revised Draft FS and the draft Remedy Selection Plan.

6.3 Alternative 2 - Baseline

Alternative 2 provides a baseline for evaluating other remedial alternatives. Alternative 2 includes extracting groundwater from two existing extraction (EW-D1-1 and EW-D1-2) wells. The extracted water would be treated at two above ground facilities and reinjected into the aquifer via three existing injection wells (IW-D1-1, IW-D1-2 and IW-D1-3). This baseline alternative corresponds to the continued operation and maintenance of the groundwater ETR systems currently under construction for the groundwater RRA.

The major components of this alternative include:

- Groundwater extraction,
- Groundwater treatment,
- Groundwater recharge,
- Operation, maintenance and monitoring,
- Institutional controls, and
- Site close out.

6.3.1 Description

Groundwater extraction is a well-established technology for removing contaminated groundwater. For Alternative 2, the groundwater would be extracted via two existing extraction wells (EW-D1-1 and EW-D1-2), treated at two treatment system locations and then reinjected at three existing injection wells (IW-D1-1, IW-D1-2 and IW-D1-3).

6.3.1.1 Introduction

The interim RRA system scheduled to be operational in September 2004 consists of two separate ETR systems (i.e., Frank Perkins Road and Pew Road) collectively referred to as the RRA System.

6.3.1.2 Assumptions

The costs and conceptual design of this alternative are based on the following assumptions:

- For all of the remedial alternatives evaluated, it is assumed that the RRA System would operate for four years until any of the full-scale systems are constructed. Therefore, there is assumed to be no costs associated for the initial installation and first four years of operation of the RRA System.

- The RRA System consists of a single mobile treatment container system at the Pew Road location and three mobile treatment container systems at the Frank Perkins Road location.

- After four years, it is assumed that the RRA treatment system at the Frank Perkins Road location (the three mobile treatment container systems) would be replaced with a full-scale treatment facility. The full-scale treatment facility would consist of a permanent structure to house the treatment equipment. The treatment train of the full-scale system would consist of an IX system for perchlorate treatment and a standard GAC system for explosive treatment. For cost estimating purposes, the GAC system has been assumed to consist of three GAC vessels sized to provide an EBCT of 10-minutes.

- The treatment system at Pew Road would continue to utilize the single mobile treatment container of the RRA treatment system. For cost estimating purposes, the mobile treatment container system would be replaced every 10 years with a new mobile treatment container system.

6.3.2 Conceptual Design

6.3.2.1 Groundwater Extraction

Extraction and injection well locations and pumping rates were determined through modeling activities prior to development of the subregional model described in this document, as discussed in the RRA Plan (AMEC, 2003c). This RRA represents a baseline condition against which more comprehensive remedial alternatives and a minimal action alternative developed in this FS are compared. The existing locations of the extraction wells and treatment facilities are presented in Figure 6-1. The projected mass removal of COCs from the aquifer is presented in Figure 6-2.

Frank Perkins Road Location

The Frank Perkins Road system includes one existing extraction well (EW-D1-1) near the center of the plume on Frank Perkins Road with two existing injection wells (IW-D1-1, IW-D1-2) located on the northern and southern edges of the plume. The design flow rate for the Frank Perkins Road system is 220 gpm.

Pew Road Location

The Pew Road system includes one existing extraction well (EW-D1-2) near the center of the plume on Pew Road with one existing injection well (IW-D1-3) located south of the plume boundary near the intersection of Pew Road and Estey Road. The design flow rate for the Pew Road system is 100 gpm.

6.3.2.2 Groundwater Treatment

The groundwater treatment processes will correspond to the fundamental treatment components of the RRA System and the previous assumptions set forth in this report. Also, the Frank Perkins Road mobile containerized treatment system would be replaced with a full-scale treatment plant contained within an engineered structure. The Pew Road system will remain unchanged from the existing RRA system (i.e., single mobile treatment container).

Frank Perkins Road Location

For the Frank Perkins Road system, groundwater treatment would consist of IX resin for the primary treatment for perchlorate and GAC media for the primary treatment of explosives. The sizing of the GAC vessels would be based on a 10 minute EBCT for the Frank Perkins Road location. The sizing of the IX system would be based on a minimum 3 foot bed depth and 6 gpm/sf. Figure 6-3 presents a process flow diagram (PFD) for Alternative 2 at Frank Perkins Road.

Pew Road Location

For the Pew Road system, groundwater treatment would consist of standard GAC media for the treatment of low levels of perchlorate. The sizing of the GAC vessels would be based on a 5 minute EBCT for the Pew Road location (consistent with the RRA system). Figure 6-4 presents a PFD for Alternative 2 at Pew Road. GAC media would address other COCs (e.g. explosives) if they were present.

6.3.2.3 Groundwater Recharge

Groundwater would be recharged to the aquifer via the three existing injection wells installed for the RRA System. The RRA Plan (AMEC, 2003b) documents the rationale for injection wells over recharge galleries or other recharge methods. Figure 6-1 shows the locations of the injections wells for both the Frank Perkins Road and Pew Road treatment systems.

Frank Perkins Road Location

Groundwater treated at the Frank Perkins Road facility would be recharged to the aquifer via the existing injection wells IW-D1-1 and IW-D1-2.

Pew Road Location

Groundwater treated via the Pew Road system would be recharged to the aquifer via the single existing injection well IW-D1-3.

6.3.2.4 Operation, Maintenance and Monitoring

Operation and maintenance activities would include replacement of the Pew Road container and replacement of pumps and motors every 10 years (i.e., 5 times over life of remedial action). Approximately 20 tons of GAC would be sent off-site for disposal and approximately 220 c.f. of IX resin would be incinerated every nine months after media change-outs for the Frank Perkins Road treatment system. Approximately 16 tons of GAC would be sent off-site for disposal annually for the Pew Road treatment system.

Long-term groundwater monitoring associated with the Demo 1 plume would continue using the same sampling and analytical protocols currently in use. Baseline monitoring of the site conditions and potential environmental impacts will be monitored according to the System Performance and Environmental Impact Monitoring (SPEIM) Plan. The SPEIM, which will be submitted to the EPA and DEP in June 2004, will outline all sampling associated with system operation and maintenance for the RRA System. The results of influent and effluent sampling of the treatment system will be used to estimate mass removal of contaminants and ensure compliance with discharge requirements.

6.3.2.5 Institutional Controls

As long as the plume area is within the sole purview and control of the Army, groundwater use restrictions are not needed. However, should the Army transfer its lease to another entity, institutional controls would be established upon lease transfer. The current lease agreement is in effect until 2052. Institutional controls could include deed restrictions that would prohibit the placement of drinking water supply wells where their zone of contribution would intercept the Demo 1 groundwater plume.

6.3.2.6 Site Closeout

Following completion of the proposed activities several measures would be taken to properly abandon and remove the system associated with this alternative. Site closeout for this alternative would include the following two actions:

- All monitoring, extraction and injection wells would be properly abandoned at the site, and
- The treatment system, including buildings, would be disassembled and removed from the site. However, subsurface piping associated with the treatment system would remain.

6.3.2.7 Schedule

The RRA system is expected to be operational in September 2004 and would continue uninterrupted through the remedy selection process. The RRA System will run until the comprehensive remedial action alternative is implemented. Design and construction of this alternative would be completed by 2008.

6.3.3 Detailed Evaluation

6.3.3.1 Overall Protection of Human Health and the Environment

Alternative 2 will prevent the migration of the plume off Camp Edwards. Groundwater fate and transport modeling of Alternative 2 indicate that perchlorate and RDX concentrations would decrease to background levels within 50 years the plume would not migrate off Camp Edwards. More than 80% of the perchlorate mass and 67% of RDX mass would be removed from the aquifer after 10 years from selection of the comprehensive remedy.

Short-term impacts would be limited. Minimal vegetation will be impacted by future construction because Alternative 2 simply entails the use of the RRA System, which is currently under construction. Establishment and adherence to a site health and safety plan would limit risk to construction workers. All contaminated media would be contained and disposed of in accordance with applicable regulations.

6.3.3.2 Compliance with Regulations

Alternative 2 would comply with applicable regulations. Supporting information is provided in Appendix D.

6.3.3.3 Long-Term Effectiveness and Permanence

Groundwater extraction and treatment will remove the COCs from groundwater permanently. However, since the intent of the extraction well locations and pumping rates was to provide hydraulic capture of the majority of the groundwater plume, the COC concentrations in groundwater will be reduced slowly. The treatment mediums would adsorb the explosives and perchlorate compounds, removing them from the water. Spent GAC would be disposed of at a permitted waste treatment facility or regenerated. Spent IX resin would also be transported off-site to a permitted waste facility, likely to be incinerated. Residual site risk is expected to be very low.

6.3.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Extraction and treatment of groundwater would reduce the toxicity, mobility and volume of the COCs at the site by removing these compounds permanently from the aquifer. The GAC media would adsorb explosives and low levels of perchlorate and the IX media would remove the perchlorate. Therefore, the treatment would reduce the mobility of the contaminants. Spent GAC media, IX resin, and other contaminated solid wastes would require removal and disposal. Approximately 13 tons of waste material would potentially be generated each year during the initial years of operation. It is anticipated that this quantity would decrease as the influent concentrations decrease over time.

6.3.3.5 Short-Term Effectiveness

There would be little effect on the community from implementing Alternative 1 because the construction work would be conducted on Camp Edwards. Material, equipment, and personnel transport would cause negligible impact on roads leading to Camp Edwards. Wastes generated from the groundwater treatment system would be trucked off-site for disposal periodically.

A site-specific health and safety plan (HASP) would be followed during system construction where engineering controls and personal protective equipment (PPE) would be used as necessary to prevent potential exposure to COCs. The potential for short-term worker exposure would increase during equipment maintenance (e.g., GAC and IX media replacement) but would be mitigated by the use of engineering controls and proper personal protective equipment (PPE).

Vegetated area clearance in order to construct the treatment facility at Frank Perkins Road has been minimized by siting the facility in already-disturbed areas.

Based on groundwater modeling results, remediation of this contaminant plume to restore the sole source aquifer to background conditions is expected to take approximately 50 years.

6.3.3.6 Implementability

Implementability involves technical feasibility, administrative feasibility, and availability of services and materials. Alternative 2 is currently being implemented as a RRA for groundwater. The system is expected to be operational in September 2004.

Installation of a treatment facility at Frank Perkins Road would be technically feasible. The extraction wells, piping, and pumps as part of the RRA System would already be installed. Standard GAC media and IX resin are available technologies and, as summarized in Appendix B, have been shown to be effective in treating the applicable COCs. In addition, the efficacy of standard GAC media and IX resin will be tested during the initial four years of operation of the RRA System.

The treatment systems would require regular maintenance and monitoring. Experience at other sites suggests that the components should be relatively reliable. If a pumping well or treatment system failed, the system might require a period of a few days to approximately two months to bring back to full operational status. The design would include an evaluation of the need for redundant systems to minimize down time in order to protect human health and the environment (AMEC, 2003b).

Long-term groundwater monitoring associated with the Demo 1 plume would continue using the same sampling and analytical protocols currently in use. Baseline monitoring of the site conditions and potential environmental impacts would be monitored according to the SPEIM Plan, which will be submitted in June 2004 and will outline all sampling associated with system operation and maintenance.

Administratively, this alternative is feasible. Critical administrative aspects of this alternative include waste classification of spent GAC media, IX resin, and other wastes, and resulting management requirements.

Services and materials are readily available. Multiple vendors can provide each component of the alternative.

If the existing lease is terminated, expires, or is transferred, deed restrictions prohibiting the installation of water supply wells within the area of impacted groundwater would be negotiated with the Commonwealth of Massachusetts. In the interim, the Army would restrict any development of drinking water supplies in areas that would be impacted by the existing groundwater plume.

6.3.3.7 Costs

The costs were estimated for Alternative 2 as follows:

- Capital cost: $ 3,640,000;
- Present worth of O & M: $11,400,000; and
- Total present worth: $15,000,000.

Appendix C provides detailed calculations of the cost of Alternative 2.

6.3.3.8 State Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process based on comments and input received from DEP, and finalized based upon comments received on this Revised Draft FS and the Draft Remedy Selection Plan.

6.3.3.9 Community Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process and finalized based on comments received on the Revised Draft FS and the draft Remedy Selection Plan.

6.4 Alternative 3 - Background

Alternative 3 is designed to contain the plume and ultimately achieve background concentrations of COCs in the aquifer. Alternative 3 includes extracting groundwater from four wells as indicated in Figure 6-5. Conceptually, the extracted water would be treated at two above ground locations and injected into the aquifer via four injection wells. The following section outlines the conceptual design of this alternative.

The major components of this alternative include:

- Groundwater extraction,
- Groundwater treatment,
- Groundwater recharge,
- Operation, maintenance and monitoring,
- Institutional controls, and

- Site close out.

6.4.1 Description

For Alternative 3 the groundwater would be extracted via four extraction wells, treated at two treatment system locations, and then reinjected at four injection wells as indicated in Figure 6-5.

Alternative 3 would operate until the concentrations of COCs in the Demo 1 plume decreased to background concentrations (For the purposes of these evaluations, "background" shall be assumed to be 0.35 μg/L for perchlorate and 0.25 μg/L for RDX).

6.4.2 Conceptual Design

6.4.2.1 Groundwater Extraction

For Alternative 3, groundwater would be extracted from a total of four extraction wells. Two existing extraction wells (EW-D1-1 and EW-D1-2) would be utilized from the RRA system and two additional extraction wells would be installed (EW-D1-401 and EW-D1-402 - see Figure 6-5 for well locations). The groundwater would be extracted using submersible electric pumps, which would also provide the necessary head to transport the groundwater through the subsurface piping to the treatment facilities.

The projected mass removal of COCs from the aquifer is presented in Figure 6-6. Table 6-1 indicates the amount of time that would be required to achieve cleanup goals, according to the groundwater model used for this FS.

Frank Perkins Road Location

Groundwater extracted from the eastern extractions wells (EW-D1-1 and EW-D1-401) would be conveyed to a new treatment facility off Frank Perkins Road located within the Former GP-15 area. This location shall be referred to as the Frank Perkins Road location. An estimated total of 264 gpm would be pumped to this treatment facility.

Pew Road Location

Groundwater extracted from the extraction wells west of Pew Road (EW-D1-2 and EW-D1-402) would be conveyed to a series of mobile treatment containers located on Pew Road. Based on the modeling results, a total of 208 gpm of groundwater would be pumped to this Pew Road location.

6.4.2.2 Groundwater Treatment

Separate treatment systems are preferable over a single treatment system for several reasons. First, the separation of flow by extraction wells upgradient and downgradient of Pew Road allows for optimal treatment design where the downgradient treatment system at Pew Road would be designed to treat very low (less than 2 μg/L) concentrations of perchlorate and possibly low concentrations of other COCs (i.e., explosives), and the upgradient system at Frank Perkins Road would be designed to treat slightly higher concentrations of perchlorate (up to 10 μg/L) and low levels of explosives.

Second, separate treatment system locations would allow for flexibility over time for system optimization. For example, as indicated in Table 6-1, the estimated time to achieve background conditions for this alternative is 21 years for the portion of the plume downgradient of Pew Road and 27 years for that portion upgradient of Pew Road. By using separate treatment systems, the downgradient Pew Road ETR system can be shut down and decommissioned earlier than the upgradient Frank Perkins Road treatment system.

Finally, the separate treatment system locations will provide an overall capital cost savings. The proposed treatment at the Pew Road location would include three mobile treatment containerized systems, which would include the existing mobile treatment container of the Pew Road RRA system and two of the mobile treatment containers from the Frank Perkins Road RRA System. Therefore, the capital costs for Pew Road would be limited to the mobilization of the two treatment containers from the Frank Perkins Road location, site work, and mechanical/electrical connection of the two relocated mobile treatment containers. This cost would be less than the cost of trenching and installing subsurface piping (either through the wooded area over the plume or along to available roadways) to the Frank Perkins Road location.

The conceptual designs presented below were based on assumptions and design parameters set forth previously in this report and in Appendix B.

Frank Perkins Road Treatment Location

As indicated in Table 6-2, the influent concentrations anticipated at the Frank Perkins Road location are 9.5 μg/L perchlorate and 8.5 μg/L RDX after one year of pumping. The anticipated concentrations would decrease in the subsequent years. The conceptual design was based on the projected concentrations after one year of pumping. The influent concentrations would likely be greater within the first year. However, it is not prudent to base the system design on the short-term initial concentrations. If these concentrations require increased media change-outs in the first year, the short-term cost for media will be offset by savings resulting from the long-term reductions in O&M costs.

The treatment train would consist of an IX system followed by a GAC system. In addition to GAC and IX resin, ancillary treatment components would include equilibrium, backwash, and settling tanks (as necessary); filtration systems; and transfer pumps as needed. This equipment would be determined during the detailed design. Figure 6-7 presents a conceptual PFD.

The IX system design would be based on a minimum three-foot bed depth and 6 gpm/ft^2. At 264 gpm, the total amount of IX media necessary would be 132 ft^3. The design would incorporate two IX vessels in series. IX cannot effectively treat explosives; therefore, the treatment system must also include GAC.

Based on the design EBCT of 10-minutes, the minimum amount of GAC necessary is approximately 11,000 pounds. The GAC system would utilize a treatment train of three vessels and GAC change out would be initiated by COC levels detected in the effluent of the second vessel. Based on the sizes of commonly-available equipment, the cost estimate is based on the use of three 10,000-pound vessels and change outs of 20,000 pounds every nine months.

Pew Road Treatment Location

The anticipated influent perchlorate concentration at the Pew Road location would be approximately 1 μg/L during the first five years of operation. The treatment system design would be the same as the existing RRA system. Figure 6-8 presents a conceptual PFD. This includes GAC treatment with each mobile treatment container utilizing six 1,000-pound vessels. The vessels in each container will be plumbed such that three 1,000-pounds vessels run in series.

The selected number of treatment containers would be based on the flow and a desired minimum 5-minute EBCT. The modeled flow rate of 208 gpm would require a total of three mobile treatment containers. This would provide the equivalent of 6,000-pounds GAC treatment with three such treatment trains in series. At 208 gpm, this would provide a 7.2-minute EBCT.

6.4.2.3 Groundwater Recharge

Groundwater would be recharged to the aquifer via the three existing injection wells installed for the RRA and one new injection well (IW-D1-4), as shown on Figure 6-5.

Frank Perkins Road Location

Groundwater treated at the Frank Perkins Road system would be recharged to the aquifer via the existing injection wells IW-D1-1 and IW-D1-2. The flow would typically be split equally between the two injection wells, or 132 gpm each.

Pew Road Location

Groundwater treated via the Pew Road system would be recharged to the aquifer via the existing injection well IW-D1-3 and one new injection well IW-D1-4. Each injection well would accept approximately 104 gpm.

6.4.2.4 Operation, Maintenance and Monitoring

Operation and maintenance activities would include disposal of treatment residuals and annual maintenance on pumps and other equipment. Approximately 20 tons of GAC would be sent off-site for disposal and approximately 260 c.f. of IX resin would be incinerated every nine months during media change-outs for the Frank Perkins Road treatment system. Approximately 48 tons of GAC would be sent off-site for disposal annually for the Pew Road treatment system.

Long-term groundwater monitoring of the Demo 1 plume would continue using the same sampling and analytical protocols currently in use. The SPEIM Plan for the RRA System, to be submitted to EPA and DEP in June 2004, would be updated to describe baseline monitoring of the site conditions and potential environmental impacts and outline all sampling associated with the system operation and maintenance for this alternative. The results of influent and effluent sampling of the treatment system would be used to estimate mass removal of contaminants and ensure compliance with discharge requirements.

6.4.2.5 Institutional Controls

As long as the plume area is within the sole purview and control of the Army, groundwater use restrictions are not needed. However, should the Army transfer its lease to another entity, institutional controls would be established upon transfer. The current lease agreement is in effect until 2052. Institutional controls could include deed restrictions that would prohibit the placement of drinking water supply wells where their zone of contribution would intercept the Demo 1 groundwater plume.

6.4.2.6 Site Closeout

Following completion of the proposed activities several measures would be taken to properly abandon and remove the system associated with this alternative. Site closeout for this alternative would include the following two actions:

- All monitoring, extraction and injection wells would be properly abandoned at the site, and
- The treatment system, including facilities, would be disassembled and removed from the site (however, subsurface piping associated with the treatment system would remain).

6.4.2.7 Schedule

The RRA system is expected to be operational in September 2004 and would continue uninterrupted through the remedy selection process. The RRA System would run until the comprehensive remedial action alternative was implemented. Design and construction of this alternative would be completed by 2008.

6.4.3 Detailed Evaluation

6.4.3.1 Overall Protection of Human Health and the Environment

This alternative would prevent the migration of the plume outside of MMR. Groundwater models indicate that background levels could be achieved in 27 years for RDX and 23 years for perchlorate.

Short-term impacts would be limited. Other than road construction to EW-D1-402, minimal vegetation would be impacted by construction since the conceptual design focuses on using existing roadways and previously disturbed areas. Establishment and adherence to a site health and safety plan would limit the risk to construction workers. All contaminated media would be contained and disposed of in accordance with applicable regulations.

6.4.3.2 Compliance with Regulations

Alternative 3 would comply with applicable regulations. Appendix D provides supporting information.

6.4.3.3 Long-Term Effectiveness and Permanence

Groundwater extraction and treatment would remove the COCs from groundwater permanently. However, the well locations and pumping rates incorporated in this alternative would primarily control groundwater contaminated above background levels, rather than remove contaminated groundwater as quickly as possible. The treatment media would adsorb the explosives and perchlorate compounds, removing them from the water. Spent carbon would be disposed of at a permitted waste treatment facility or regenerated. Spent IX resin would also be transported off-site to a permitted waste facility, likely to be incinerated. The residual site risk is expected to be very low.

6.4.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Extraction and treatment of groundwater would reduce the toxicity, mobility and volume of the COCs at the site by removing these compounds permanently from the aquifer. Explosives and low levels of perchlorate would be adsorbed by the GAC media and perchlorate would be removed by the IX resin. Thus, treatment would reduce the mobility of the contaminants. Spent GAC media, IX resin, and other contaminated solid wastes would require removal and disposal. Approximately 39 tons of waste material would potentially be generated each year.

6.4.3.5 Short-Term Effectiveness

There would be little effect on the community from implementing Alternative 3 because the construction work would be conducted on Camp Edwards. Material, equipment, and personnel transport would cause negligible impact on roads leading to Camp Edwards. Wastes generated from the groundwater treatment system would be trucked off-site for disposal periodically.

A site-specific HASP would be followed during system construction where engineering controls and PPE would be used as necessary to limit potential exposure to COCs. To date, health and safety precautions at Demo 1 for UXO clearance, soil excavation, construction activities, groundwater sampling, and drilling have been adequate to protect workers. The potential for short-term worker exposure would increase during equipment maintenance (e.g., GAC media and IX resin replacement) but would be mitigated by the use of engineering controls and proper PPE.

To the extent feasible, previously disturbed areas have been utilized for the installation of wells, subsurface piping and treatment facilities to minimize impact on cultural and natural resources. However, a significant length of vegetation clearance would be required for the installation of subsurface piping from EW-D1-402 to the Pew Road Treatment Facility.

Based on groundwater modeling results, remediation of this contaminant plume to restore the sole source aquifer to background conditions is expected to take approximately 27 years.

6.4.3.6 Implementability

Implementability involves technical feasibility, administrative feasibility, and availability of services and materials. Each factor is discussed briefly below.

Installation of extraction wells, pumps, piping, and treatment facilities at Frank Perkins Road and Pew Road would be technically feasible. GAC and IX are available technologies and, as summarized in Appendix B, have been shown to be effective in treating the COCs.

The treatment systems would require regular maintenance and monitoring. Experience at other sites suggests that the components should be relatively reliable. If a pumping well or treatment system failed, the system might require a period of a few days to approximately two months to bring back to full operational status. If this alternative were selected for implementation, the design would include an evaluation of the need for redundant systems to minimize down time in order to protect human health and the environment.

Long-term groundwater monitoring associated with the Demo 1 plume would continue using the same sampling and analytical protocols currently in use. Sampling and monitoring would be easily implemented.

Administratively, this alternative would be feasible. Critical administrative aspects of this alternative would include:

- Preparation of a Record of Action;

- Waste classification of spent GAC media, IX resin, and other wastes, and resulting management requirements.

Services and materials are readily available. Multiple vendors can provide each component of the alternative.

If the existing lease is terminated, expires, or is transferred, deed restrictions prohibiting the installation of water supply wells within the area of impacted groundwater would be negotiated with the Commonwealth of Massachusetts. In the interim, the Army would restrict any development of drinking water supplies in areas that would be impacted by the existing groundwater plume.

6.4.3.7 Costs

The costs were estimated for Alternative 3 as follows:

- Capital cost: $ 5,620,000;
- Present worth of O & M: $14,700,000; and
- Total present worth: $20,300,000.

Appendix C provides detailed calculations for the cost of Alternative 3.

6.4.3.8 State Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process based on comments and input received from DEP, and finalized based upon comments received on this Revised Draft FS Report and the Draft Remedy Selection Plan.

6.4.3.9 Community Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process and finalized based on comments received on the Revised Draft FS and the draft Remedy Selection Plan.

6.5 Alternative 4 – 10 Year

Alternative 4 is designed to achieve risk-based clean up goals in approximately 10 years. Alternative 4 includes extracting groundwater from five extraction wells for treatment at two above ground locations and then injecting treated groundwater into the aquifer via four injection wells. The major components of this alternative include:

- Groundwater extraction,
- Groundwater treatment,
- Groundwater recharge,
- Operation, maintenance and monitoring,
- Institutional controls, and
- Site close out.

6.5.1 Description

The groundwater would be extracted via five extraction wells, treated at two treatment system locations and then reinjected at four injection wells as indicated in Figure 6-9. Alternative 4 would operate until the concentrations of COCs in the Demo 1 plume had been reduced to risk-based cleanup goals.

6.5.2 Conceptual Design

6.5.2.1 Groundwater Extraction

Groundwater would be extracted from five extraction wells. Two existing extraction wells (EW-D1-1 and EW-D1-2) would be utilized from the RRA system and three additional extraction wells would be installed (EW-D1-501, EW-D1-502, and EW-D1-503) as shown on Figure 6-9 along with the locations of subsurface piping and treatment facilities. The groundwater would be extracted using submersible electric pumps, which would also provide the necessary head to transport the groundwater through the subsurface piping to the treatment facilities. The subsurface piping would be of single wall plastic construction. The conceptual locations of the extractions wells, subsurface piping and treatment facilities are indicated in Figure 6-9.

Figure 6-10 shows the projected mass removal of COCs from the aquifer. Table 6-1 indicates the amount of time that would be required to achieve cleanup goals, according to the groundwater model used for this FS.

Frank Perkins Road Location

Groundwater extracted from the eastern extraction wells (EW-D1-1, EW-D1-501, EW-D1-502, EW-D1-503) would be pumped to the Frank Perkins Road location. Based on modeling results, the total pumping rate would be 1,196 gpm.

Pew Road Location

Groundwater extracted from the well at Pew Road (EW-D1-2) would be conveyed to a treatment facility located on Pew Road. Based on the modeling results a total of 221 gpm of groundwater would be pumped to this location.

6.5.2.2 Groundwater Treatment

As did Alternative 3, Alternative 4 incorporates separate treatment systems at Pew Road and Frank Perkins Road. See Section 6.3.2 for the rationale behind that decision. The conceptual design of the groundwater treatment processes was based on assumptions and design parameters set forth previously in this report and in Appendix B.

Frank Perkins Road Treatment Location

As indicated in Table 6-2, the influent concentrations anticipated at the Frank Perkins Road location are 3.7 μg/L perchlorate and 3.1 μg/L RDX after one year of pumping. The anticipated concentrations would decrease in the subsequent years. As described in Section 6.3.2.2 for Alternative 3, the size of the treatment equipment in the conceptual design is based on the estimated influent concentrations one year after startup.

The treatment train would consist of an IX system followed by a GAC system. Ancillary treatment components would include equilibrium, backwash, and settling tanks; filtration system; and transfer pumps as needed. This equipment would be determined during the detailed design. Figure 6-11 presents a conceptual PFD for the Frank Perkins Road system.

The IX system design would be based on a minimum three-foot bed depth and 6 gpm/ft^2. At 1,196 gpm, the total amount of IX media necessary would be approximately 600 ft^3. The design would incorporate a minimum of two IX vessels in series. (Note that the actual IX system may include additional treatment vessels based on the hydraulic design of the vessels). IX treatment is not effective for explosives; therefore, GAC treatment would also be necessary.

Based on the design EBCT of 10-minutes, the minimum amount of GAC necessary would be approximately 48,000 pounds. The GAC system would utilize a treatment train of three vessels and GAC change out would be initiated by COC levels detected in the effluent of the second vessel. Based on the sizes of readily-available equipment, the cost estimate is based on the use of two sets of three 20,000-pound vessels and one set of three 10,000-pound vessels. Operation of this system would entail change-outs of 100,000 pounds of carbon every nine months.

Pew Road Treatment Location

The anticipated influent perchlorate concentration at the Pew Road location is 1.0 μg/L after one year of pumping. The treatment system design would be the same as the existing RRA system. Figure 6-12 presents a conceptual PFD for the Pew Road system. The selected number of treatment containers would be based on the flow and a desired minimum 5-minute EBCT. For the modeled 221 gpm, this alternative would use a total of three mobile treatment containers. This would provide the equivalent of 6,000-pounds GAC treatment with three such trains in series. At 221 gpm, this would provide a 6.8-minute EBCT.

6.5.2.3 Groundwater Recharge

Groundwater would be recharged to the aquifer via the three existing injection wells installed for the RRA System and one new injection well (IW-D1-4) as shown in Figure 6-9.

Frank Perkins Road Location

Groundwater treated at the Frank Perkins Road system would be recharged to the aquifer via the two existing injection wells IW-D1-1 and IW-D1-2. The flow would typically be split equally between the two injection wells, or 597 gpm each.

Pew Road Location

Groundwater treated via the Pew Road system will be recharged to the aquifer via the existing injection well IW-D1-3 and a new injection well IW-D1-4. The flow would typically be split equally between the two injection wells, or 110 gpm each.

6.5.2.4 Operation, Maintenance and Monitoring

Operation and maintenance activities would include disposal of treatment residuals and annual maintenance on pumps and other equipment. Approximately 100 tons of GAC would be sent off-site for disposal and approximately 1,200 c.f. of IX resin would be incinerated every nine months during media change-outs for the Frank Perkins Road treatment system. Approximately 48 tons of GAC would be sent off-site for disposal annually for the Pew Road treatment system.

The SPEIM Plan for the RRA System, to be submitted to EPA and DEP in June 2004, would be updated to describe baseline monitoring of the site conditions and potential environmental impacts and outline all sampling associated with the system operation and maintenance for this alternative.

6.5.2.5 Institutional Controls

As long as the plume area is within the sole purview and control of the Army, groundwater use restrictions are not needed. However, should the Army transfer its lease to another entity, institutional controls would be established upon transfer. The current lease agreement is in effect until 2052. Institutional controls could include deed restrictions that would prohibit the placement of drinking water supply wells where their zone of contribution would intercept the Demo 1 groundwater plume.

6.5.2.6 Site Closeout

Following completion of the proposed activities several measures would be taken to properly abandon and remove the system associated with this alternative. Site closeout for this alternative would include the following two actions:

- All monitoring, extraction and injection wells would be properly abandoned at the site, and
- The treatment system, including facilities, would be disassembled and removed from the site (however, subsurface piping associated with the treatment system would remain).

6.5.2.7 Schedule

The RRA system is expected to be operational in September 2004 and would continue uninterrupted through the remedy selection process. The RRA System would run until the comprehensive remedial action alternative was implemented. Design and construction of this alternative would be completed by 2008.

6.5.3 Detailed Evaluation

6.5.3.1 Overall Protection of Human Health and the Environment

This alternative would aggressively remove contaminated groundwater from Demo 1, achieving risk-based levels in just over 10 years according to the groundwater model used for this FS. For perchlorate, target concentrations would be achieved in less than 10 years. For RDX, target concentrations would be achieved in just over 10 years; after 10 years of operation, an estimated 99.7% of the RDX mass would have been captured.

Short-term impacts would be limited. Other than road construction to EW-D1-503, minimal vegetation would be impacted by construction since the conceptual design focuses on using existing roadways and previously disturbed areas. Establishment and adherence to a site health and safety plan would limit risk to construction workers. All contaminated media would be contained and disposed of in accordance with applicable regulations.

6.5.3.2 Compliance with Regulations

Alternative 4 would comply with applicable regulations. Appendix D provides supporting information.

6.5.3.3 Long-Term Effectiveness and Permanence

Groundwater extraction and treatment will remove the COCs from groundwater permanently. Based on the design objective for this alternative, the COC concentrations in groundwater would decrease quickly. The treatment media would adsorb the explosives and perchlorate compounds, removing them from the water. Spent carbon would be disposed of at a permitted waste treatment facility or regenerated. Spent IX resin would also be transported off-site to a permitted waste facility, likely to be incinerated. The residual site risk is expected to be very low.

6.5.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Extraction and treatment of groundwater would reduce the toxicity, mobility and volume of the COCs at the site by removing these compounds permanently from the aquifer. Explosives and low levels of perchlorate would be adsorbed by the GAC media and perchlorate would be removed by the IX resin. Therefore, this treatment would reduce the mobility of the contaminants. Spent GAC, IX resin, and other solid contaminated wastes would require removal and disposal. Approximately 93 tons of waste material would potentially be generated each year.

6.5.3.5 Short-Term Effectiveness

Alternative 4 would have little effect on the community because the construction work would be conducted on Camp Edwards. Material, equipment, and personnel transport would cause negligible impact on roads leading to Camp Edwards. Wastes generated from the groundwater treatment system would be trucked off-site for disposal periodically.

A site-specific HASP would be followed during system construction. Workers would use engineering controls and PPE as necessary to control potential exposure to COCs. To date, health and safety precautions at Demo 1 for UXO clearance, soil excavation, construction activities, groundwater sampling, and drilling have been adequate to protect workers. The potential for short-term worker exposure would increase during equipment maintenance (e.g., GAC media and IX resin replacement) but would be mitigated by the use of engineering controls and proper PPE.

To the extent feasible, previously disturbed areas have been utilized for the installation of wells, subsurface piping and treatment facilities to minimize impact on cultural and natural resources.

Based on groundwater modeling results, remediation of this contaminant plume to restore the sole source aquifer to risk-based levels is expected to take approximately 11 years.

6.5.3.6 Implementability

Implementability involves technical feasibility, administrative feasibility, and availability of services and materials. Each factor is discussed briefly below.

Installation of extraction wells, pumps, piping and treatment facilities at the Frank Perkins Road and Pew Road locations would be technically feasible. GAC and IX are available technologies and, as summarized in Appendix B, have been shown to be effective in treating the applicable COCs.

The treatment systems would require regular maintenance and monitoring. Experience at other sites suggests that the components should be relatively reliable. If a pumping well or treatment system failed, the system might require a period of a few days to approximately two months to bring back to full operational status. If this alternative were selected for implementation, the design would include an evaluation of the need for redundant systems to minimize down time in order to protect human health and the environment.

Long-term groundwater monitoring associated with the Demo 1 plume would continue using the same sampling and analytical protocols currently in use. Influent and effluent sampling of the treatment system would also take place to estimate mass removal of contaminants and ensure compliance with discharge requirements. Sampling and monitoring would be easily implemented.

Administratively, this alternative would be feasible. Critical administrative aspects of this alternative would include:

- Preparation of a Record of Action;

- Waste classification of spent GAC, IX resin and other wastes, and resulting management requirements.

Services and materials are readily available. Multiple vendors can provide each component of the alternative.

If the existing lease is terminated, expires, or is transferred, deed restrictions prohibiting the installation of water supply wells within the area of impacted groundwater would be negotiated with the Commonwealth of Massachusetts. In the interim, the Army would restrict any development of drinking water supplies in areas that would be impacted by the existing groundwater plume.

6.5.3.7 Costs

The costs were estimated for Alternative 4 as follows:

- Capital cost: $10,200,000;
- Present worth of O & M: $15,500,000; and
- Total present worth: $25,700,000.

Appendix C provides detailed calculations for the cost of Alternative 4.

6.5.3.8 State Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process based on comments and input received from DEP and finalized based upon comments received on this Revised Draft FS Report and the Remedy Selection Plan.

6.5.3.9 Community Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process and finalized based on comments received on the Revised Draft FS and the draft Remedy Selection Plan.

6.6 Alternative 5 - Additional Alternative A

The goal of this alternative is to achieve risk-based cleanup goals in a timeframe that approaches an optimal trade-off between capital and O&M costs. Alternative 5 includes extracting groundwater from five extraction wells, treating the water at two above-ground facilities, and injecting treated water into the aquifer via four injection wells. The major components of this alternative include:

- Groundwater extraction,
- Groundwater treatment,
- Groundwater recharge,
- Operation, maintenance and monitoring,
- Institutional controls, and
- Site close out.

6.6.1 Description

For Alternative 5, the groundwater would be extracted via five extraction wells, treated at two treatment systems and then re-injected at four injection wells as indicated in Figure 6-9.

Alternative 5 would operate until the concentrations of COCs in the Demo 1 plume had been reduced to risk-based cleanup goals (see Table 6-1).

6.6.2 Conceptual Design

6.6.2.1 Groundwater Extraction

For Alternative 5, groundwater would be extracted from five extraction wells: two existing extractions wells (EW-D1-1 and EW-D1-2) and three additional extraction wells that would be installed (EW-D1-501, EW-D1-502, and EW-D1-503). The groundwater would be extracted using submersible electric pumps, which would also provide the necessary head to transport the groundwater through the subsurface piping to the treatment facilities. The subsurface piping would be of single wall construction. The conceptual locations of the extractions wells, subsurface piping and treatment facilities are indicated in Figure 6-13.

Figure 6-14 shows the projected mass removal of COCs from the aquifer. Table 6-1 indicates the amount of time that would be required to achieve cleanup goals, according to the groundwater model used for this FS.

Frank Perkins Road Location

Groundwater extracted from eastern extraction wells (EW-D1-1, EW-D1-501, EW-D1-502, EW-D1-503) would be pumped to a treatment facility at the Frank Perkins Road location. Based on the modeling results, a total of 808 gpm would be conveyed to this treatment facility.

Pew Road Location

Groundwater extracted from the extraction well at Pew Road (EW-D1-2) would be conveyed to a treatment facility located on Pew Road. Based on the modeling results a total of 98 gpm of groundwater would be pumped to this location.

6.6.2.2 Groundwater Treatment

The groundwater treatment processes would be based on assumptions and design parameters set forth previously in this report and in Appendix B. For the reasons described previously, extracted groundwater would be treated at two separate plants.

Frank Perkins Road Treatment Location

As indicated in Table 6-2, the influent concentrations anticipated at the Frank Perkins Road location would be 5.3 μg/L perchlorate and 4.6 μg/L RDX after one year of pumping. The anticipated concentrations would decrease in the subsequent years. As described previously, the estimated concentrations at year 1 were used as the basis for the conceptual design of treatment units.

The conceptual treatment system would consist of an IX system followed by a GAC system. Ancillary treatment components would include equilibrium, backwash and settling tanks, filtration system and transfer pumps as needed. This equipment would be determined during the detailed design. Figure 6-15 presents a conceptual PFD.

The IX system design would be based on a minimum three foot bed depth and 6 gpm/ft^2. At 806 gpm, the total amount of IX media necessary would be approximately 400 ft^3. The design would incorporate two IX vessels in series. IX treatment is not effective for explosives; therefore, GAC treatment would also be necessary.

Based on the design EBCT of 10-minutes and the modeled flow rate of 806 gpm, the minimum amount of GAC necessary would be approximately 33,000 pounds. The GAC system would utilize a treatment train of three vessels. GAC change-out would be initiated by COC levels detected in the effluent of the second vessel. Based on the sizes of commonly available equipment, the cost estimate is based on the use of two sets of three 20,000-pound vessels and change outs of 80,000 pounds every nine months.

Pew Road Treatment Location

The anticipated influent concentration at the Pew Road location is 1.4 μg/L after one year of pumping. The treatment system design would be the same as the existing RRA system. Figure 6-16 presents a conceptual PFD. The number of treatment containers would be based on the flow rate and a desired minimum 5-minute EBCT. For the modeled 98 gpm flow rate, this alternative would use one mobile treatment container system. At 98 gpm, this would provide a 5.1-minute EBCT.

6.6.2.3 Groundwater Recharge

Groundwater would be recharged to the aquifer via the three injection wells installed for the RRA System and one new injection well (IW-D1-4), as indicated in Figure 6-13.

Frank Perkins Road Location

Groundwater treated at the Frank Perkins Road system would be recharged to the aquifer via the existing injection wells IW-D1-1 and IW-D1-2. The flow would typically be split equally between the two injection wells, or 404 gpm each.

Pew Road Location

Groundwater treated via the Pew Road system would be recharged to the aquifer via the existing injection well IW-D1-3 and one new injection well IW-D1-4. The flow would typically be split equally between the two injection wells, or 49 gpm each.

6.6.2.4 Operation, Maintenance and Monitoring

Operation and maintenance activities would include disposal of treatment residuals and annual maintenance on pumps and other equipment. Approximately 80 tons of GAC would be sent off-site for disposal and approximately 800 c.f. of IX resin would be incinerated every nine months during media change-outs for the Frank Perkins Road treatment system. Approximately 16 tons of GAC would be sent off-site for disposal annually for the Pew Road treatment system.

The SPEIM Plan for the RRA System, to be submitted to EPA and DEP in June 2004, would be updated to describe baseline monitoring of the site conditions and potential environmental impacts and outline all sampling associated with the system operation and maintenance for this alternative.

6.6.2.5 Institutional Controls

As long as the plume area is within the sole purview and control of the Army, groundwater use restrictions are not needed. However, should the Army transfer its lease to another entity, institutional controls would be established upon transfer. The current lease agreement is in effect until 2052. Institutional controls could include deed restrictions that would prohibit the placement of drinking water supply wells where their zone of contribution would intercept the Demo 1 groundwater plume.

6.6.2.6 Site Closeout

Following completion of the proposed activities several measures would be taken to properly abandon and remove the system associated with this alternative. Site closeout for this alternative would include the following two actions:

- All monitoring, extraction and injection wells would be properly abandoned at the site, and
- The treatment system, including facilities, would be disassembled and removed from the site (however, subsurface piping associated with the treatment system would remain).

6.6.2.7 Schedule

The RRA system is expected to be operational in September 2004 and would continue uninterrupted through the remedy selection process. The RRA System would run until the comprehensive remedial action alternative was implemented. Design and construction of this alternative would be completed by 2008.

6.6.3 Detailed Evaluation

6.6.3.1 Overall Protection of Human Health and the Environment

This alternative would prevent the migration of the plume off-base and remove contaminant mass from the groundwater plume. Target concentrations would be achieved in less than 14 years for RDX and 13 years for perchlorate, according to the modeling performed for this FS.

Short-term impacts would be limited. Other than road construction to EW-D1-503, minimal vegetation would be impacted by construction since the conceptual design focuses on using existing roadways and previously disturbed areas. Establishment of and adherence to a site health and safety plan would limit the risk to construction workers. All contaminated media would be contained and disposed of in accordance with applicable regulations.

6.6.3.2 Compliance with Regulations

Alternative 5 would comply with applicable regulations. Appendix D provides supporting information.

6.6.3.3 Long-Term Effectiveness and Permanence

Groundwater extraction and treatment will remove the COCs from groundwater permanently. Since the design focuses on aggressively extracting and treating groundwater to meet the remedial objective, the COC concentrations in groundwater would be reduced relatively quickly. The treatment media would adsorb the explosives and perchlorate compounds, removing them from the water. Spent carbon would be disposed of at a permitted waste treatment facility or regenerated. Spent IX resin would also be transported off-site to a permitted waste facility, likely to be incinerated. The residual site risk is expected to be very low.

6.6.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Extraction and treatment of groundwater would reduce the toxicity, mobility and volume of the COCs at the site by removing these compounds permanently from the aquifer. Explosives and low levels of perchlorate would be adsorbed by the GAC media and perchlorate would be removed by the IX resin. Therefore, this alternative would reduce the mobility of the contaminants. Spent GAC, IX resin, and other solid contaminated wastes would require removal and disposal. Approximately 58 tons of waste material would potentially be generated each year.

6.6.3.5 Short-Term Effectiveness

There would be little effect on the community from implementing this Alternative because the construction work would be conducted on Camp Edwards. Material, equipment, and personnel transport would cause negligible impact on roads leading to Camp Edwards. Wastes generated from the groundwater treatment system would be trucked off-site for disposal periodically.

A site-specific HASP would be followed during system construction where engineering controls and PPE would be used as necessary to limit potential exposure to COCs. To date, health and safety precautions at Demo 1 for UXO clearance, soil excavation, construction activities, groundwater sampling, and drilling have been adequate to protect workers. The potential for short-term worker exposure would increase during equipment maintenance (e.g., GAC media and IX resin replacement) but would be mitigated by the use of engineering controls and proper PPE.

To the extent feasible, previously disturbed areas have been utilized for the installation of wells, subsurface piping and treatment facilities to minimize impact on cultural and natural resources.

Based on groundwater modeling results, remediation of this contaminant plume to restore the sole source aquifer to risk-based levels is expected to take approximately 14 years.

6.6.3.6 Implementability

Implementability involves technical feasibility, administrative feasibility, and availability of services and materials. Each factor is discussed briefly below.

Installation of extraction wells, pumps, piping and a treatment facility at the Frank Perkins Road location would be technically feasible. GAC and IX are available technologies and, as summarized in Appendix B, have been shown to be effective in treating the applicable COCs.

The treatment systems would require regular maintenance and monitoring. Experience at other sites suggests that the components should be relatively reliable. If a pumping well or treatment system failed, the system might require a period of a few days to approximately two months to bring back to full operational status. If this alternative were selected for implementation, the design would include an evaluation of the need for redundant systems to minimize down time in order to protect human health and the environment.

Long-term groundwater monitoring associated with the Demo 1 plume would continue using the same sampling and analytical protocols currently in use. Influent and effluent sampling of the treatment system would also take place to estimate mass removal of contaminants and ensure compliance with discharge requirements. Sampling and monitoring would be easily implemented.

Administratively, this alternative would be feasible. Critical administrative aspects of this alternative would include:

- Preparation of a Record of Action;
- Waste classification of spent GAC, IX resin and other wastes, and resulting management requirements.

Services and materials are readily available. Multiple vendors are available for each component of the alternative.

If the existing lease is terminated, expires, or is transferred, deed restrictions prohibiting the installation of water supply wells within the area of impacted groundwater would be negotiated with the Commonwealth of Massachusetts. In the interim, the Army would restrict any development of drinking water supplies in areas that would be impacted by the existing groundwater plume.

6.6.3.7 Costs

The costs were estimated for Alternative 5 as follows:

- Capital cost: $ 8,340,000;
- Present worth of O & M: $12,700,000; and
- Total present worth: $21,000,000.

Appendix C provides detailed calculations of the cost of Alternative 5.

6.6.3.8 State Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process based on comments and input received from DEP and finalized based upon comments received on this Revised Draft FS Report and the Remedy Selection Plan.

6.6.3.9 Community Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process and finalized based on comments received on the Revised Draft FS and the draft Remedy Selection Plan.

6.7 Alternative 6 - Additional Alternative B

The primary objective of Alternative 6 is to restore the groundwater to background conditions in a similar timeframe to other more aggressive alternatives (Alternative 5). Alternative 6 includes extracting groundwater from six extraction wells, treating the water at two above ground facilities, and reinjecting treated water into the aquifer via four injection wells. The major components of this alternative include:

- Groundwater extraction,
- Groundwater treatment,
- Groundwater recharge,
- Operation, maintenance and monitoring,
- Institutional controls, and
- Site close out.

6.7.1 Description

For Alternative 6, the groundwater would be extracted via six extraction wells, treated at two treatment system locations, for the reasons described previously, and then re-injected at four injection wells as indicated in Figure 6-17.

Alternative 6 would operate until the concentrations of COCs in the Demo 1 plume had been reduced to background conditions (for the purposes of these evaluations, “background” shall be assumed to be 0.35 μg/L for perchlorate and 0.25 μg/L for RDX).

6.7.2 Conceptual Design

6.7.2.1 Groundwater Extraction

Groundwater would be extracted from a total of six extraction wells, including two existing extractions wells (EW-D1-1 and EW-D1-2) four additional wells (EW-D1-601, EW-D1-602, EW-D1-603, and EW-D1-604). The groundwater would be extracted using submersible electric pumps, which would also provide the necessary head to transport the groundwater through the subsurface piping to the treatment facilities. The subsurface piping would be of single wall construction. The conceptual locations of the extractions wells, subsurface piping and treatment facilities are indicated in Figure 6-17.

Figure 6-18 shows the projected mass removal of COCs from the aquifer over time. Table 6-1 indicates the amount of time that would be required to achieve cleanup goals, according to the groundwater model used for this FS.

Frank Perkins Road Location

Groundwater extracted from eastern extraction wells (EW-D1-1, EW-D1-601, EW-D1-602, EW-D1-603 and EW-D1-604) would be pumped to a treatment facility at the Frank Perkins Road location. Based on the modeling results, a total of 808 gpm would be conveyed to this treatment facility.

Pew Road

Groundwater extracted from the extraction wells west of Pew Road (EW-D1-2 and EW-D1-604) would be conveyed to a treatment facility located on Pew Road. Based on the modeling results a total of 87 gpm of groundwater would be pumped to this location.

6.7.2.2 Groundwater Treatment

The design of the groundwater treatment processes would be based on assumptions and design parameters set forth previously in this report and in Appendix B.

Frank Perkins Road Treatment Location

As indicated in Table 6-2, the influent concentrations anticipated at the Frank Perkins Road location are 5.4 μg/L perchlorate and 4.6 μg/L RDX after one year of pumping. The anticipated concentrations would decrease in the subsequent years. For the reasons discussed previously, the estimated concentrations after one year of pumping were utilized as the conceptual design basis.

The proposed treatment train would consist of an IX system followed by a GAC system. In addition to GAC media and IX resin, ancillary treatment components would include equilibrium, backwash and settling tanks; filtration system; and transfer pumps as needed. This equipment would be determined during the detailed design. Figure 6-19 presents a conceptual PFD.

The IX system conceptual design was based on a minimum three foot bed depth and 6 gpm/ft^2. At 808 gpm, the total amount of IX media necessary would be approximately 400 ft^3. The design would incorporate two IX vessels in series. IX treatment is not effective for explosives; therefore, the treatment system would also include GAC.

Based on the design EBCT of 10-minutes and the modeled flow rate of 808 gpm, the minimum amount of GAC necessary would be approximately 33,000 pounds. The GAC system would utilize a treatment train of three vessels. GAC change-out would be initiated by COC levels detected in the effluent of the second vessel. Based on the sizes of typically available equipment, the cost estimate is based on the use of two sets of three 20,000-pound vessels and change outs of 80,000 pounds of GAC every nine months.

Pew Road Treatment Location

The anticipated influent concentration at the Pew Road location is 0.9 μg/L after one year of pumping. The treatment system design would be the same as the RRA system. Figure 6-20 presents a conceptual PFD. The number of treatment containers would be based on the flow rate and a desired minimum 5-minute EBCT. For the modeled 173 gpm flow, this alternative would require two mobile treatment container systems. At 173 gpm, this would provide a 5.8-minute EBCT.

6.7.2.3 <u>Groundwater Recharge</u>

Groundwater would be recharged to the aquifer via the three existing injection wells installed for the RRA System and one new injection well (IW-D1-4), as indicated in Figure 6-17.

Frank Perkins Road Location

Groundwater treated at the Frank Perkins Road system would be recharged to the aquifer via the existing injection wells IW-D1-1 and IW-D1-2. The flow would typically be split equally between the two injection wells, or 404 gpm each.

Pew Road Location

Groundwater treated via the Pew Road system would be recharged to the aquifer via the existing injection well IW-D1-3 and a new injection well IW-D1-4. The flow would typically be split equally between the two injection wells, or 87 gpm each.

6.7.2.4 <u>Operation, Maintenance and Monitoring</u>

Operation and maintenance activities would include disposal of treatment residuals and annual maintenance on pumps and other equipment. Approximately 80 tons of GAC would be sent off-site for disposal and approximately 800 c.f. would be incinerated every nine months during media change-outs for the Frank Perkins Road treatment system. Approximately 32 tons of GAC would be sent off-site for disposal annually for the Pew Road treatment system.

The SPEIM Plan for the RRA System, to be submitted to EPA and DEP in June 2004, would be updated to describe baseline monitoring of the site conditions and potential environmental impacts and outline all sampling associated with the system operation and maintenance for this alternative.

6.7.2.5 Institutional Controls

As long as the plume area is within the sole purview and control of the Army, groundwater use restrictions are not needed. However, should the Army transfer its lease to another entity, institutional controls would be established upon transfer. The current lease agreement is in effect until 2052. Institutional controls could include deed restrictions that would prohibit the placement of drinking water supply wells where their zone of contribution would intercept the Demo 1 groundwater plume.

6.7.2.6 Site Closeout

Following completion of the proposed activities several measures would be taken to properly abandon and remove the system associated with this alternative. Site closeout for this alternative would include the following two actions:

- All monitoring, extraction and injection wells would be properly abandoned at the site, and
- The treatment system, including facilities, would be disassembled and removed from the site (however, subsurface piping associated with the treatment system would remain).

6.7.2.7 Schedule

The RRA system is expected to be operational in September 2004 and would continue uninterrupted through the remedy selection process. The RRA System would run until the comprehensive remedial action alternative was implemented. Design and construction of this alternative would be completed by 2008.

6.7.3 Detailed Evaluation

6.7.3.1 Overall Protection of Human Health and the Environment

This alternative would prevent the migration of the plume off-base and remove contaminant mass from the groundwater plume. According to the groundwater model, background levels would be achieved in 16 years for RDX and 17 years for perchlorate.

Short-term impacts would be most significant with this alternative. Road construction and piping installation to EW-D1-603 and to EW-D1-604 cuts through previously undisturbed vegetation. These areas would be impacted by construction even though the conceptual design focuses on using existing roadways and previously disturbed areas. The placement of the extraction wells are located a considerable distance from the nearest roadway and/or previously disturbed areas and involves clearance of over 2,000 feet of road. Roadway construction involves a 15 ft width of vegetation clearance and trenching involves 10 ft of vegetation clearance. Establishment and adherence to a site health and safety plan would limit risk to construction workers. All contaminated media would be contained and disposed of in accordance with applicable regulations.

6.7.3.2 Compliance with Regulations

Alternative 6 would comply with applicable regulations. Appendix D provides supporting information.

6.7.3.3 Long-Term Effectiveness and Permanence

Groundwater extraction and treatment would remove the COCs from groundwater permanently. Since the design focuses on aggressively extracting and treating groundwater to meet the remedial objective, the COC concentrations in groundwater would be reduced quickly. The treatment media would adsorb the explosives and perchlorate compounds, removing them from the water. Spent GAC media would be disposed of at a permitted waste treatment facility or regenerated. Spent IX resin would also be transported off-site to a permitted waste facility, potentially for incineration. The residual site risk is expected to be very low.

6.7.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Extraction and treatment of groundwater would reduce the toxicity, mobility and volume of the COCs at the site by removing these compounds permanently from the aquifer. Explosives and low levels of perchlorate would be adsorbed by the GAC media and perchlorate would be removed by the IX resin. Therefore this treatment would reduce the mobility of the contaminants. Spent GAC, IX resin, and other solid contaminated wastes would require removal and disposal. Approximately 62 tons of waste material would potentially be generated each year.

6.7.3.5 Short-Term Effectiveness

Alternative 6 would have little effect on the community because the construction work would be conducted on Camp Edwards. Material, equipment, and personnel transport would cause negligible impact on roads leading to Camp Edwards. Wastes generated from the groundwater treatment system would be trucked off-site for disposal periodically.

A site-specific HASP would be followed during system construction. Workers would use engineering controls and PPE as necessary to limit potential exposure to COCs. To date, health and safety precautions at Demo 1 for UXO clearance, soil excavation, construction activities, groundwater sampling, and drilling have been adequate to protect workers. The potential for short-term worker exposure would increase during equipment maintenance (e.g., GAC media and IX resin replacement) but would be mitigated by the use of engineering controls and proper PPE.

To the extent feasible, previously disturbed areas have been utilized for the installation of wells, subsurface piping and treatment facilities to minimize impact on cultural and natural resources. However, a significant length of vegetation clearance would be required for the installation of subsurface piping from EW-D1-603 to the Frank Perkins Treatment Facility and from EW-D1-604 to the Pew Road Treatment Facility.

Based on groundwater modeling results, remediation of this contaminant plume to restore the sole source aquifer to background conditions is expected to take approximately 17 years.

6.7.3.6 Implementability

Implementability involves technical feasibility, administrative feasibility, and availability of services and materials. Each factor is discussed briefly below.

Installation of extraction wells, pumps, piping and treatment facilities at Frank Perkins Road and Pew Road would be technically feasible. GAC and IX are available technologies and, as summarized in Appendix B, have been shown to be effective in treating the applicable COCs.

The treatment systems would require regular maintenance and monitoring. Experience at other sites suggests that the components should be relatively reliable. If a pumping well or treatment system failed, the system might require a period of a few days to approximately two months to bring back to full operational status. If this alternative were selected for implementation, the design would include an evaluation of the need for redundant systems to minimize down time in order to protect human health and the environment.

Long-term groundwater monitoring associated with the Demo 1 plume would continue using the same sampling and analytical protocols currently in use. Sampling and monitoring would be easily implemented.

Administratively, this alternative would be feasible. Critical administrative aspects of this alternative would include:

- Preparation of a Record of Action;

- Waste classification of spent GAC, IX resin and other wastes, and resulting management requirements.

Services and materials are readily available. Multiple vendors can provide each component of the alternative.

If the existing lease is terminated, expires, or is transferred, deed restrictions prohibiting the installation of water supply wells within the area of impacted groundwater would be negotiated with the Commonwealth of Massachusetts. In the interim, the Army would restrict any development of drinking water supplies in areas that would be impacted by the existing groundwater plume.

6.7.3.7 Costs

The costs were estimated for Alternative 6 as follows:

- Capital cost: $ 9,860,000;
- Present worth of O & M: $16,700,000; and
- Total present worth: $26,600,000.

Appendix C provides detailed calculations of the cost for Alternative 6.

6.7.3.8 State Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process based on comments and input received from DEP, and finalized based upon comments received on this Revised Draft FS and the Draft Remedy Selection Plan

6.7.3.9 Community Acceptance

This criterion will be continuously evaluated throughout the development and screening of alternatives process and finalized based on comments received on the Revised Draft FS and the draft Remedy Selection Plan.

7.0 COMPARATIVE ANALYSIS

A comparative analysis was conducted to evaluate the relative performance of each alternative in relation to each criterion. This section of the report describes the results of that analysis in narrative and tabular form. The presentation of the comparative analysis refers to each alternative by its number. For reference, a brief description of each alternative follows:

- Alternative 1 – Minimal Action. Alternative 1 provides a minimal action alternative for comparison with other alternatives. This alternative includes long-term groundwater monitoring and institutional controls.

- Alternative 2 – Baseline. Alternative 2 provides a baseline alternative for comparison with other alternatives. This alternative includes the continued operation of the RRA Systems for approximately 50 years until COCs are reduced to background concentrations. Alternative 2 would entail pumping groundwater at a total flow rate of approximately 320 gpm from two locations, treatment via IX resin to remove perchlorate and GAC media to remove explosive compounds, and recharge of treated water via three injection wells. This alternative also includes long-term groundwater monitoring and institutional controls.

- Alternative 3 - Background. Alternative 3 includes a total of four extraction wells (including the two RRA extraction wells) located along the plume axis and pumping at a combined flow rate of 472 gpm. This pumping scheme is designed to achieve background concentrations for the COCs in a reasonable timeframe (i.e., less than 30 years). Similar to Alternative 2, a combination of IX resin and GAC media would be used to treat the extracted water, however a fourth injection well would be added to recharge the treated water to the aquifer. This alternative also includes long-term groundwater monitoring and institutional controls.

- Alternative 4 - 10 Year. Alternative 4 includes a total of five extraction wells (including the two RRA extraction wells) located along the plume axis and pumping at a combined flow rate of 1,417 gpm. This alternative is the most aggressive cleanup scenario, designed to achieve risk-based cleanup goals for the COCs within 10 years. Similar to Alternative 3, a combination of IX resin and GAC media would be used to treat the extracted water and four injection wells would be used to recharge the treated water to the aquifer. This alternative also includes long-term groundwater monitoring and institutional controls.

- Alternative 5 - Additional Alternative A. Alternative 5 includes a total of five extraction wells (including the two RRA extraction wells) located along the plume axis and pumping at a combined flow rate of 906 gpm. This alternative could achieve regulatory or risk-based standards for the COCs in approximately 14 years, according to model simulations and this alternative approaches an optimal trade-off between capital and O&M costs. Similar to Alternative 3, a combination of IX resin and GAC media would be used to treat the extracted water and four injection wells would be used to recharge the treated water to the aquifer. This alternative also includes long-term groundwater monitoring and institutional controls.

- Alternative 6 - Additional Alternative B. Alternative 6 includes a total of six extraction wells (including the two RRA extraction wells) located along the plume axis and pumping at a combined flow rate of 981 gpm. Alternative 3 provides an alternative that could achieve background concentrations for the COCs in approximately 17 years. Similar to Alternative 3, a combination of IX resin and GAC media would be used to treat the extracted water and four injection wells would be used to recharge the treated water to the aquifer. This alternative also includes long-term groundwater monitoring and institutional controls.

EPA guidance (USEPA, 1988) suggests the FS report should describe the strengths and weaknesses of each alternative and notes that an effective way to present this information is in a narrative that addresses each criterion. The alternative(s) that could perform best overall in each category is presented first, followed by other alternatives discussed in the relative order of potential performance. For ease of review, Table 7-1 presents a summary of the detailed analysis.

7.1 Overall Protection of Human Health and the Environment

All alternatives have the potential to protect human health and the environment. Alternative 4 would remediate the aquifer most quickly. Alternatives 3 through 6 would be more reliable than Alternative 1, a minimal action alternative, or Alternative 2, which primarily acts as a hydraulic containment measure rather than focusing on relatively rapid mass removal.

7.2 Compliance with Regulations

All of the alternatives could potentially comply with the applicable regulations. The regulations for each alternative are similar because each alternative includes groundwater extraction, ex-situ treatment, and recharge components. See Appendix D for a description of regulatory considerations and the actions to be taken in consideration.

7.3 Long-Term Effectiveness and Permanence

Alternatives 3 through 6 could all permanently and effectively achieve the clean-up goals in the long-term. Of these, Alternative 4 would reach risk-based cleanup goals the most quickly. Alternatives 5 and 6 are moderate alternatives, which still reach the objectives quickly (estimated <20 years) but are less aggressive than Alternative 4 in terms of total extraction flow rate. Alternatives 2 and 3 could potentially achieve background conditions in 50 and 27 year timeframes, respectively. Alternative 1 would not achieve background conditions within the aquifer.

All Alternatives under consideration, except Alternative 1, are adequate to protect human health and the environment since they prevent the Demo 1 groundwater plume from migrating off-base. Institutional controls would be established to protect future site users and off-base residents by precluding groundwater development in any groundwater supply wells' zone of contribution.

7.4 Reduction of Toxicity, Mobility, or Volume through Treatment

All alternatives would reduce the toxicity, mobility, or volume of contaminated groundwater through treatment. Alternatives 4, 5 and 6 would more rapidly treat groundwater by removing most of the dissolved mass in a 10-year timeframe.

7.5 Short-Term Effectiveness

None of the alternatives are expected to have significant short-term impacts on the community since the construction activities would be restricted to Camp Edwards. Alternative 1 would have the least short-term impact on the community since it involves no further action, except for long-term groundwater monitoring and institutional controls.

Alternative 6 would cause the greatest environmental impact to surrounding vegetation (natural resources) with six wells and associated piping. Alternatives 4 and 5, each with five wells and associated piping, would have the next greatest impact on natural resources. None of the alternatives are expected to have negative cultural/historical impacts as the Demo 1 area is in a low sensitivity area at MMR.

Alternative 4 could potentially reach risk-based cleanup goals for all COCs within the aquifer in 11 years. However, Alternative 6 would get to background levels within the aquifer in 15 years upgradient of Pew Road and in 17 years downgradient of Pew Road.

7.6 Implementability

Alternative 2 is the most easily implemented alternative since the RRA System, comprising a large portion of this alternative, will already be implemented. None of the alternatives are limited by administrative or technical feasibility.

7.7 Cost

Based on the order of magnitude cost estimates and underlying assumptions, Alternative 1 is the most cost-effective option. Note that some of the costs for this alternative have been incurred under the RRA System for groundwater and are not reflected in the costs for the comprehensive remedial action. Alternatives 3 and 5 are the next most cost effective alternatives, estimated to achieve background concentrations in 27 years or risk-based concentrations in 14 years.

Alternative 1 has the lowest capital cost since it is a minimal action alternative. Alternative 2 has the next lowest capital cost. Operation and maintenance costs for Alternative 2 would be spread over 50 years of system operation. The cost of Alternative 2 does not factor in costs allocated for the RRA System. Alternative 3 has the next lowest capital cost. Operation and maintenance costs for Alternative 3 would be spread over 27 years of system operation. Alternative 4 has the highest capital cost. Operation and maintenance of the system described in Alternative 4 would be spread over 11 years.

7.8 State Acceptance

This criterion will be addressed in detail following comments on the Revised Draft FS and Remedy Selection Plan.

7.9 Community Acceptance

This criterion will be addressed in detail following comments on the Revised Draft FS and Remedy Selection Plan.

8.0 CONCLUSIONS

This Revised Draft FS describes the development and detailed analysis of remedial action alternatives for groundwater at Demo 1. After resolution of comments on the Revised Draft FS and receipt of input from the public, a Remedy Selection Plan will be developed that documents the proposed remedial action alternative.

8.1 Conclusions

The following conclusions can be made based on the detailed and comparative analysis of alternatives presented in this Revised Draft FS.

- All the Alternatives, except Alternative 1, would be protective of human health and the environment.
- All the Alternatives, except Alternative 1, would comply with applicable regulations.
- Alternative 4 would achieve the risk-based cleanup goals in the shortest timeframe (approximately 10 years).
- Alternative 5 is estimated to be the most cost-effective in comparison with other alternatives and would achieve risk-based concentrations within the plume in approximately 14 years.

8.2 Schedule

The current schedule to select a remedial alternative for the Demo 1 Groundwater OU is provided below.

Activity	Date
Submit Final FS	08/23/04
Submit Draft Remedy Selection Plan to Agencies/IART	09/21/04
Submit Final Remedy Selection Plan for Public Comment	12/28/04
End Public Comment Period	01/31/05
Submit Draft Decision Document and Responsiveness Summary	04/26/05
Submit Final Decision Document and Responsiveness Summary	07/28/05

Design activities would be initiated after USEPA approval of the selected Remedial Alternative. The anticipated activities and duration for design and remediation as required by AO3 are provided in Table 8-1.

9.0 REFERENCES

Ainsworth, C. C., S. D. Harvey, J. E. Szecsody, M. A. Simmons, V. I. Cullinan, C. T. Resch, and G. H. Mong. 1993. Relationship Between the Leachability Characteristics of Unique Energetic Compounds and Soil Properties. Project Order No. 91PP1800. Pacific Northwest Laboratory, Richland, WA for U. S. Army Biomedical Research and Development Laboratory. Fort Detrick Frederick, MD.

AMEC, 2000a. Final Feasibility Study Work Plan. Massachusetts Military Reservation Cape Cod, Massachusetts. December 2000. AMEC Earth and Environmental, Westford Massachusetts.

AMEC, 2001a. Final IAGWSP Technical Team Memorandum 01-2 Demo 1 Groundwater Report. Massachusetts Military Reservation Cape Cod, Massachusetts. April 2001. AMEC Earth and Environmental, Westford Massachusetts.

AMEC, 2001b. Draft IAGWSP Technical Team Memorandum 01-10, Demo 1 Soil Report. Massachusetts Military Reservation Cape Cod, Massachusetts. June 7, 2001. AMEC Earth and Environmental, Westford Massachusetts.

AMEC, 2001c. Revised Final ITE Groundwater Treatability Summary – AO3. Massachusetts Military Reservation, Cape Cod, Massachusetts. August 31, 2001. AMEC Earth and Environmental, Westford, Massachusetts.

AMEC, 2001d. Technical Team Memorandum 01-17, Draft Feasibility Study, Demo 1 Groundwater Operable Unit. Massachusetts Military Reservation, Cape Cod, Massachusetts. October, 2001. AMEC Earth and Environmental, Westford, Massachusetts.

AMEC, 2001e. Final IAGWSP Technical Team Memorandum 01-5, Development and Initial Screening of Alternatives Report Demo 1 Groundwater OU. Massachusetts Military Reservation, Cape Cod, Massachusetts. AMEC Earth and Environmental, Westford, Massachusetts.

AMEC, 2002a. Letter from Marc Grant (AMEC) to Todd Borci (EPA) and Len Pinaud (MADEP). Subject: Long Term Groundwater Quality Monitoring (LTGM) Plan for 2002, Memorandum of Resolution for December 2002 Event. December 4, 2002. AMEC Earth and Environmental, Inc. Westford MA.

AMEC, 2002b. Draft Innovative Technology Evaluation Groundwater Treatability Study Summary: Fluidized Bed Reactor Study #2. Camp Edwards, Massachusetts Military Reservation, Cape Cod, Massachusetts. November 2002. AMEC Earth and Environmental, Inc. Westford, MA

AMEC, 2002c. Final Innovative Technology Evaluation Groundwater Treatability Study Summary: Fluidized Bed Reactor Study Camp Edwards, Massachusetts Military

Reservation, Cape Cod, Massachusetts. November 2002. AMEC Earth and Environmental, Inc. Westford, MA

AMEC, 2002d. Draft IAGWSP Technical Team Memorandum 02-3 Aquifer Test Summary Report Central Impact Area Groundwater Post Screening Investigation. Camp Edwards, Massachusetts Military Reservation, Cape Cod Massachusetts. November 2002. AMEC Earth and Environmental, Inc. Westford, Massachusetts.

AMEC, 2003a. Draft Rapid Response Action/Release Abatement Measure (RRA/RAM) Plan, Demo 1 Groundwater Operable Unit, Camp Edwards, Massachusetts Military Reservation. January 2003. AMEC Earth and Environmental, Inc. Westford, MA.

AMEC, 2003b. Draft Rapid Response Action (RRA) Plan, Demo 1 Soil Operable Unit, Camp Edwards, Massachusetts Military Reservation. July 2003. AMEC Earth and Environmental, Inc. Westford, MA.

AMEC, 2003 c. Innovative Technology Evaluation Groundwater Treatability Study Summary: Rapid Small Scale Column Tests #1, Demo 1 Groundwater Operable Unit, Camp Edwards, Massachusetts Military Reservation. AMEC Earth and Environmental, Inc. Westford, MA.

AMEC, 2003d. Treatment Media Evaluation Frank Perkins Road Extraction, Treatment and Recharge (ETR) System Demo 1 Groundwater Operable Unit, December 23, 2003. Camp Edwards, Massachusetts Military Reservation. AMEC Earth and Environmental, Inc. Westford, MA.

AMEC, 2003e. Feasibility Study Scoping Meeting – Minutes, September 11, 2003. Camp Edwards, Massachusetts Military Reservation. AMEC Earth and Environmental, Inc. Westford, MA.

AMEC, 2004a. Final Demo 1 Groundwater Report Addendum to Technical Memorandum (TM) 01-2, Demo 1 Groundwater Operable Unit, Camp Edwards, Massachusetts Military Reservation. April 2004. AMEC Earth and Environmental, Inc., Westford, MA.

AMEC, 2004b. Innovative Technology Evaluation Groundwater Treatability Study Summary: Rapid Small Scale Column Tests #2, Demo 1 Groundwater Operable Unit, Camp Edwards, Massachusetts Military Reservation. AMEC Earth and Environmental, Inc. Westford, MA.

AMEC, 2004c. Draft Long-Term Groundwater Monitoring Plan, Camp Edwards, Massachusetts Military Reservation. April 2004. AMEC Earth and Environmental, Inc. Westford, MA.

Ashford, R.D. Ashford's Dictionary of Industrial Chemicals. London, England: Wavelength Publications Ltd., 1994.

Butler, J. J., and Garnett, E.J., 2000, Simple Procedures for Analysis of Slug Tests in Formations of High Hydraulic Conductivity using Spreadsheet and Scientific Graphics Software, Kansas Geological Survey, Open-file Report 2000-40.

DuBois, F. W. and J. F. Baytos. 1972. Effect of Soil and Weather on the Decomposition of Explosives. LA-4943. Los Alamos National Laboratory, Los Alamos, NM.

Haderlein, S. B., K. W. Weissmahr, and R. P. Schwarzenbach. 1996. Specific adsorption of nitroaromatic explosives and pesticides to clay minerals. Environmental Science and Technology. 30:612-622.

IAGWSP, 2001. Letter from Benjamin Gregson (IAGWSP) to Len Pinaud (DEP). Subject: Immediate Response Action (IRA) Completion Report for Demo 1 Soil. January 8, 2001. IAGWSP, National Guard Bureau, Camp Edwards, Massachusetts Military Reservation.

IAGWSP, 2003. Letter from Kent Gonser (IAGWSP) to Todd Borci (EPA) and Len Pinaud (DEP). Subject: Adequate Plume Characterization of Demo 1 Groundwater Operable Unit. April 18, 2003. IAGWSP, National Guard Bureau, Camp Edwards, Massachusetts Military Reservation.

Leake, S. A., and D. V. Claar. 1999. Procedures and Computer Programs for Telescopic Mesh Refinement Using MODFLOW96. USGS Open-File Report 99-238. U. S. Geological Survey. Reston, VA.

Leggett, D. C. 1985. Sorption of Military Explosive Contaminants on Bentonite Drilling Muds. CRREL Report 85-18. U. S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH.

Leggett, D. C. 1991. Role of Donor-Acceptor Interactions in the Sorption of TNT and Other Nitroaromatics from Solution. CRREL 91-13, U. S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, NH.

Levy, B.S., and Pannell, L., 1991, Evaluation of a Pressure System for Estimating In-Situ Hydraulic Conductivity, Fifth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods, Book 5, 31-45.

MAARNG, 2000. Immediate Response Action (IRA) Plan, Demolition Area 1 – Massachusetts Military Reservation, MADEP Release Tracking Number 4-15031. April 19, 2000. Impact Area Groundwater Study Office, MAARNG, Camp Edwards, MA.

MADEP, 2001. Draft Technical Team Memorandum 01-17 Feasibility Study Report, Demo 1 Groundwater Operable Unit, Comments. November 20, 2001. Commonwealth of Massachusetts, Department of Environmental Protection, Southeast Regional Office.

MADEP, 2003. Letter from Len Pinaud (DEP) to Kent Gonser (IAGWSPO), Subject: Adequate plume characterization for the purposes of the Demo 1 Groundwater Feasibility Study. May 21, 2003. USEPA, Region 1, Boston, MA.

Masterson, J. P., D. A. Walter, and J. Savoie. 1996. Use of Particle Tracking to Improve Numerical Model Calibration and to Analyze Groundwater Flow and Contaminant Migration, Massachusetts Military Reservation Western Cape Cod, Massachusetts. USGS Open-File Report 96-214. U. S. Geological Survey. Marlborough, MA.

McLane, G.A., Harrity, D.A. and Thomsen, K.O, 1990, A Pneumatic Method for Conducting Rising and Falling Head Tests in Highly Permeable Aquifers, Fourth National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods, Book 2, 1219-1231.

Myers, T. E., J. M. Brannon, J.C. Pennington, W.M. Davis, K.F. Myers, D.M. Townsend, M.K. Ochman, and C.A. Hayes. 1998. Laboratory Studies of Soil Sorption/Transformation of TNT, RDX, and HMX. Technical Report IRRP 98-8. U.S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, MS.

Ogden, 1997. Final Field Sampling Plan for Groundwater for the Camp Edwards Impact Area Groundwater Quality Study Massachusetts Military Reservation Cape Cod, Massachusetts. October 28, 1997 and November 13, 1997. Ogden Environmental and Energy Services. Westford, MA.

Ogden, 1998a. Draft Completion of Work Report for the Camp Edwards Impact Area Groundwater Quality Study Massachusetts Military Reservation Cape Cod, Massachusetts. July 1, 1998. Ogden Environmental and Energy Services, Westford, Massachusetts.

Ogden, 1998b. Demolition Area 1 Immediate Response Plan, Camp Edwards Impact Area Groundwater Quality Study Massachusetts Military Reservation Cape Cod, Massachusetts. May 1998. Ogden Environmental and Energy Services, Westford, Massachusetts.

Ogden. 1998c. Workplan for Completion of Phase I Activities, Camp Edwards Impact Area Groundwater Quality Study Massachusetts Military Reservation Cape Cod, Massachusetts. September 1998. Ogden Environmental and Energy Services, Westford, Massachusetts.

Ogden, 1999a. Response Plan for Demolition Area 1, for the Camp Edwards Impact Area Groundwater Quality Study Massachusetts Military Reservation Cape Cod, Massachusetts. Final July 13, 1999. Ogden Environmental and Energy Services, Westford, Massachusetts.

Ogden, 1999b. Final Field Sampling Plan for Phase II (a) Drilling to Investigate RDX Exceedances for the Camp Edwards Impact Area Groundwater Quality Study Massachusetts Military Reservation Cape Cod, Massachusetts. April 12, 1999. Ogden Environmental and Energy Services. Westford, MA.

Ogden, 2000a. Final IAGS Technical Team Memorandum 99-2 Deep Soil Sampling of Demolition Area 1 Camp Edwards Impact Area Groundwater Quality Study, Massachusetts Military Reservation Cape Cod, Massachusetts. March 5, 2000. Ogden Environmental and Energy Services, Westford, Massachusetts.

Ogden, 2000b. Supplemental Soil Investigation for Demo 1, Massachusetts Military Reservation Cape Cod, Massachusetts. October 16, 2000. Ogden Environmental and Energy Services, Westford, Massachusetts.

Ogden, 2000c. Draft Final COC Identification Process. Camp Edwards Impact Area Groundwater Quality Study, Massachusetts Military Reservation Cape Cod, Massachusetts. October 26, 2000. Ogden Environmental and Energy Services, Westford, Massachusetts.

Pennington, J. C. 1988. Plant Uptake of 2,4,6-Trinitrotoluene, 4-amino-2,6-Dinitrotoluene, and 2-amino-4,6-Dinitrotoluene using 11C-labeled and Unlabeled Compounds. Technical Report EL-88-20. U. S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, MS.

Purolite, 2004. Personal communication between Katherine Weeks of AMEC and Francis Boodoo of Purolite. February 10, 2004.

Rodacy, P. and P. Leslie. 1992. Ion Mobility Spectroscopy as a Means of Detecting Explosives in Soil Samples. SAND92-13226. Sandia National Laboratories. Albuquerque, NM.

Speitel, Ge. E., H. Yamamoto, R. L. Autenrieth, and T. McDonald. Laboratory Fate and Transport Studies of High Explosives at the Massachusetts Military Reservation. Final Report prepared for AMEC Earth and Environmental, Inc., Westford, MA. 2002.

Tetra Tech, 2000. Munitions Survey Project Draft Report. National Guard Bureau. Massachusetts Military Reservation, Cape Cod, Massachusetts. October 26, 2000. Tetra Tech Inc.

Tetra Tech, 2001. Demolition Area 1 Geophysical Investigation Letter Report. National Guard Bureau. Massachusetts Military Reservation, Cape Cod, Massachusetts. October 19, 2001. Tetra Tech Inc.

Textron, 2000. Resource Conservation and Recovery Act (RCRA) 3007 Response Report. Massachusetts Military Reservation, Cape Cod, Massachusetts. July 12, 2000. Harding Lawson Associates.

Townsend, D. M. and T. E. Meyers. 1996. Recent Developments in Formulating Model Descriptors for Subsurface Transformation and Sorption of TNT, RDX, and HMX. Technical Report IRRP-96- 1. U. S. Army Corps of Engineers, Waterways Experiment Station. Vicksburg, MS.

U.S. Army Corps of Engineers and U.S. EPA, 2002. Guide to Developing and Documenting Cost Estimates During the Feasibility Study. EPA 540-R-00-002. July 2000.

USEPA, 1988. Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERLCLA, Interim Final. EPA/540/G-89/004. Office of Solid Waste and Emergency Response, Washington, DC. October 1988.

USEPA, 2000. National Secondary Drinking Water Regulations, CFR 40, Subpart 143, July 1, 2000. http://www.epa.gov/safewater/mcl.html

USEPA, 2001. Letter from Todd Borci (EPA) to Benjamin Gregson (IAGWSPO). Subject: Relevant Standard for Perchlorate in Accordance With EPA Administrative Order SDWA 1-2000-0014 (AO3). November 5, 2001. USEPA, Region 1, Boston, MA.

USEPA, 2002. 2002 Edition of the Drinking Water Standards and Health Advisories. EPA 822-R-02-038 http://www.epa.gov/safewater/mcl.html, updated Summer 2002, Washington DC, US EPA.

USEPA, 2003a. Letter from Todd Borci (EPA) to Benjamin Gregson (IAGWSPO), Subject: 1999 Interim Guidance for Perchlorate. USEPA, Region 1, Boston, MA.

USEPA, 2003b. Letter from Todd Borci (EPA) to Kent Gonser (IAGWSPO), Subject: Adequate plume characterization for the purposes of the Demo 1 Groundwater Feasibility Study. May 6, 2003. USEPA, Region 1, Boston, MA.